UNIVERSITEIT GENT

FACULTY OF SCIENCES

Take a look at the landscape!

An eye-tracking study of landscape observation and its influencing factors.

Dissertation submitted in accordance with the requirements for the degree of Doctor of Sciences: Geography

Lien Dupont

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VOORWOORD

Hier zit ik dan, op de trein, kijkend naar het landschap… Het landschap dat mij altijd al geïntrigeerd heeft, zes jaar lang het onderwerp van mijn doctoraat was waar ik mij met veel passie op heb toegelegd en waarvan ik alles wou te weten komen. Ik herinner me nog goed wanneer 'de vonk' oversloeg. In tweede bachelor, toen we voor Inleiding Landschapskunde een opdracht kregen om van een welbepaald landschap een geïntegreerde kartering te maken. Het terreinwerk, in de buitenlucht zijn, de kleinste details nauwgezet karteren, goed kijken naar het landschap en dan alles in een paper met foto's en kaarten neerschrijven. Ja, dit is het, dacht ik toen. De opdracht was mij op het lijf geschreven. Net als de andere landschapskundige opdrachten die in de latere jaren volgden. Waar ik voordien zeker en vast van het landschap genoot, ging ik toch met een heel andere blik naar het landschap kijken naarmate mijn studies vorderden en er telkens weer een nieuwe wereld openging. Het landschap bleef mij boeien, verveelde nooit. In die mate zelfs dat ik geen seconde twijfelde toen de weg naar een doctoraat open lag. Het landschap had als onderwerp zóveel te bieden dat zes jaar onderzoek nog te kort zou zijn om er echt het fijne van te weten. En kijk nu, bijna zes jaar later is dit waarheid gebleken. Hoewel ik al die jaren met de grootste passie dag in dag uit als onderzoeker met het landschap bezig ben geweest, kan ik wel zeggen dat het aanvoelt alsof ik binnen mijn onderzoeksthema 'landschapsperceptie' nog maar het topje van de ijsberg heb onderzocht. Er rest nog zoveel te doen, zoveel te verkennen, zoveel te leren… Toch ben ik voldaan over hetgene ik volbracht heb. Ik zou nog uren, dagen, weken, maanden en zelfs jaren kunnen verderwerken aan mijn doctoraat zonder mij ooit te vervelen, maar vandaag rond ik het af. Het is mooi geweest en ik ben trots op hetgeen ik vandaag kan voorleggen.

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Lien

Ergens tussen Gent en Liedekerke, 13 mei 2016

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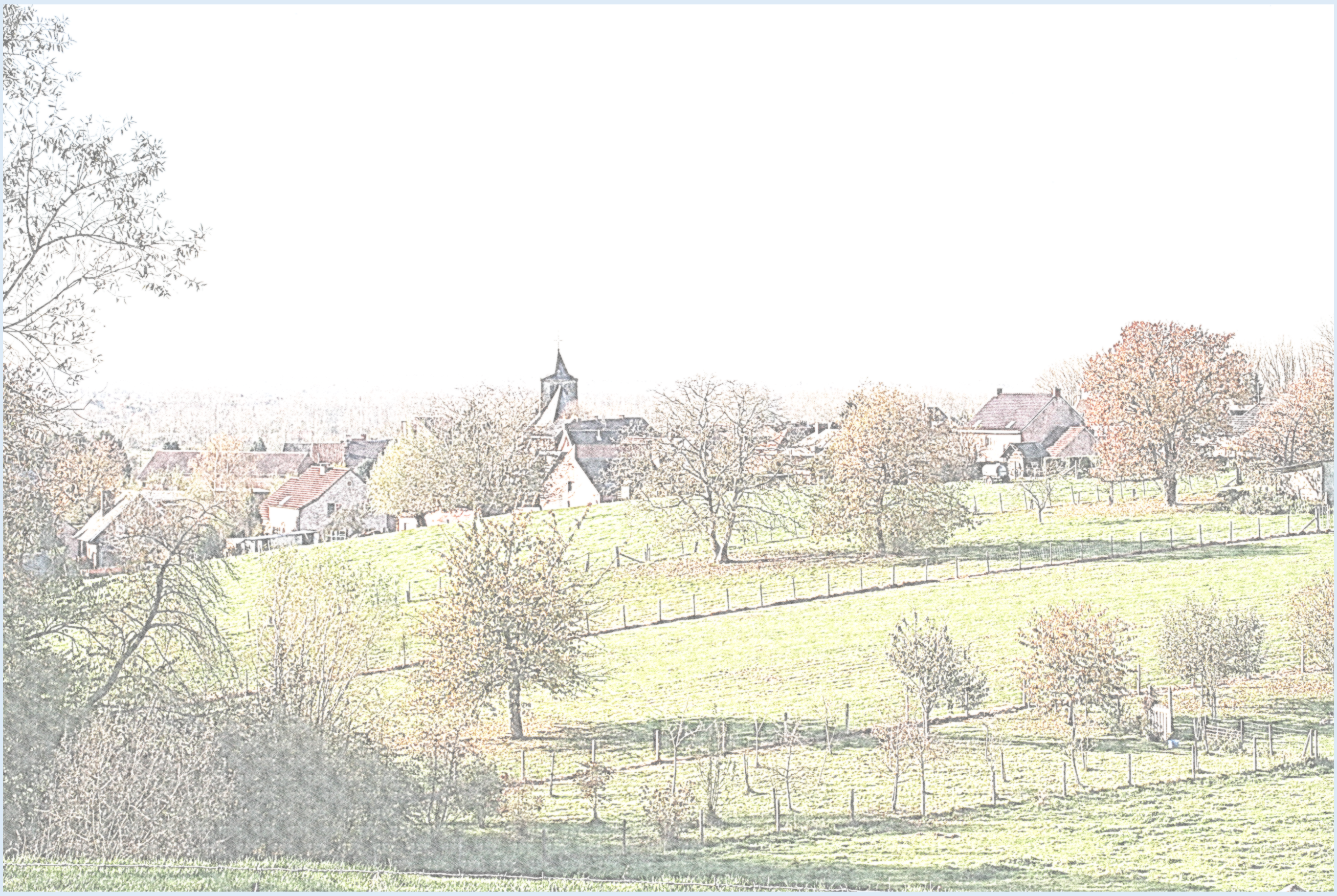
PART I

GENERAL INTRODUCTION



CHAPTER 1: UNDERSTANDING AND STUDYING LANDSCAPE PERCEPTION

As suggested in the title, the main objective of this dissertation is to investigate how people look at landscape photographs and how different factors influence this observation. In particular, the viewing behaviour in landscape photographs is examined using eye-tracking experiments in which participants are asked to observe a number of landscape photographs. During the tests, eye movements are recorded and information about the attention allocation is obtained. The effect of three factors is examined: the practical context, the characteristics of the landscape and the background of the observer. More specifically, the aim is to determine whether and how the view angles of the photographs as a specific practical factor, the degree of openness and complexity of the landscape and the level of expertise of the observer influence the viewing pattern when observing landscape photographs. The importance of the results for landscape perception research in general and more specifically the implications of the type of photograph used to study landscape perception are described. The results are also placed in the broader theoretical context of landscape perception, including evolutionary theories such as the Prospect-Refuge theory, the Information-processing theory etc. Finally, the usefulness of the findings in landscape planning and design is discussed. An eye-tracking related application for visual assessment of construction in the landscape, based on attention predicting saliency maps, is proposed and validated. In the following subchapters, an introduction is provided in which the background information relevant for understanding this thesis is described. First, we summarize how 'landscape perception', as the broader context in which landscape observation should be placed, is defined and which factors influence it. Second, the most important evolutionary theories in landscape perception and experience are described. Third, the role of visual landscape perception is situated in the context of landscape planning and design. Fourth, a detailed description of the eye-tracking technology, including an overview of the contemporary systems and domains of applications as well as its use in landscape perception studies, is provided. Finally, this introduction is concluded with a description of the motivation and a detailed presentation of the objectives of the presented research along with the outline of the dissertation.

1.1 LANDSCAPE PERCEPTION

1.1.1 Definitions and context

The topic of landscape encapsulated a broad range of topics, a sum of which describes the environment in which we live. It comprises more aspects than one would initially think of. In fact, it can be regarded as a concept with a variety of meanings with respect to culture, science, time, patterns, processes, history, identity, art, experiences, perception etc. The word ‘landscape’ has multiple meanings which can, for example, refer to a bordered territory, a scenery, a territorial identity, an expression of human ideas and beliefs etc. (Antrop, 2013). Landscape is thus not only a phenomenon resulting of complex processes which can be objectively and scientifically analysed. It also comprises subjective observation and experience which is related to landscape’s perceptive, aesthetic, artistic and existential meaning (Lowenthal, 1975; Cosgrove and Daniels, 1988). As a consequence, landscape is the subject of interest to a myriad of disciplines such as landscape ecology, historical geography, archaeology, human geography, landscape architecture, amongst others (Antrop, 2013).

In the most strict sense landscape can be defined as

“(…) the appearance of the land at the interface of the earth’s surface and atmosphere”.

(Unwin, 1975, p.130)

According to this definition, landscape principally consists of the visual aspects of all present land parameters. Landscape is in this respect determined by the shape of the earth’s surface, the topography, by the land-use features superimposed on it and by their spatial arrangement relative to the each other (Unwin, 1975).

The most widely accepted definition is given by the Council of Europe (2000), which defines landscape as

“(…) an area as *perceived by people*, whose character is the result of the action and interaction of natural and/or human factors”.

This definition takes ‘perception’ into account, stating that landscape only becomes tangible when it is *perceived*. However, some clarity is needed about what exactly is meant with ‘perception’ and ‘perceiving’. A review of definitions in scientific and popular terms reveals that perception is not an unequivocal concept, but instead has multiple meanings which can be divided into three main groups. The first group defines perception as the process of purely noticing or sensing something through the physical senses. This is what is called ‘sensation’ by Reid (1970). It refers to the process of bringing information from the environment, sensed through sight, sound, touch, smell and taste, to the brain. Some examples of definitions are:

“A process by which the human organism informs itself about objects and the processes that are exhibited in them, via the sensorial configuration of informative stimuli” (Maciá, 1979).

“Conscious sensory experience” (Goldstein, 2013).

“The process of perceiving something with the senses” (The American Heritage Dictionary of the English Language).

“The ability to notice something by seeing, hearing, smelling etc.” (macmillandictionary.com).

“The process of perceiving, becoming aware of something via the senses” (vocabulary.com).

“Awareness of the elements of environment through physical sensation” (Merriam-webster.com).

“The quality of being aware of things through the physical senses, especially sight” (Cambridge dictionaries online).

According to Granö (1997) and Howard (2013) the visual is paramount in landscape perception (research). While we know that sight accounts for 87% of the information gained by our senses (Bell, 2004), we can state that ‘perception’ is similar in meaning to ‘observation’ as defined by Merriam-webster.com which states that perception is

“The result of perceiving: observation”.

A second group extends the definition of ‘perception’ by attaching processes of understanding or interpretation to the basic act of observation. In this respect, perception is more than a physiological process as it also includes mental processes. According to Reid (1970), perception is the process of interpreting and organizing information extracted from sensations to make sense of them. Examples of similar definitions are as follows:

“The activity carried out by the brain by which we interpret what the senses (mainly sight for most people) receive. It is not merely a factual reporting but tends to be referenced to associations and expectation already present in the mind of the beholder” (Bell, 2004).

“The organization, identification, and interpretation of sensory information in order to represent and understand the environment” (Schacter et al., 2011)

“The act of perceiving or the ability to perceive; mental grasp of objects, qualities etc. by means of the senses; awareness; comprehension; the understanding, knowledge etc. gotten by perceiving” (Webster’s New World College Dictionary)

“The act or faculty of perceiving, or apprehending by means of the senses or of the mind; cognition; understanding” (Dictionary.com)

“The way that you notice or understand something using one of your senses; physical sensation interpreted in the light of experience; quick, acute, and intuitive cognition, a capacity for comprehension” (Merriam-webster.com)

“Awareness, comprehension or an understanding of something” (yourdictionary.com)

Finally, ‘perception’ can also solely refer to the result of an interpretation or understanding process:

“An interpretation or impression; an opinion or belief; Insight or knowledge gained by thinking” (The American heritage dictionary of the English Language)

“A mental image; concept” (Merriam-webster.com)

In the same context, verbs associated with perception also need to be clearly defined as they can carry slightly different connotations or subtle meanings which are important for a good understanding of this dissertation. Examples of such verbs are ‘to look’, ‘to observe’, ‘to view’, ‘to watch’, ‘to perceive’, ‘to see’ etc. While all carry the same literal meaning of “*to make use of the sense of sight, especially in a given direction or on a given object*” (Merrian-wester.com; The American heritage dictionary of the English Language), especially the latter two also often include a notion of interpretation and understanding of the observed object (e.g. *“to grasp mentally”* (Merriam-webster.com)*, “to achieve understanding of; apprehend”, “to have a mental image of”* (The American heritage dictionary of the English Language)). We can thus summarize that *looking at* something or *observing* something does not necessarily mean that the object is also *seen* by the observer in the sense that the item has definitely been remarked by the eyes but not necessarily been understood by the observer.

In this dissertation, perception will be approached in its broadest sense (second group of definitions), in which it encompasses a physiological and a psychological component: the *senses* and the *mind* respectively. In particular, the visual perception of landscape photographs – how these are actually observed, viewed, looked at – will be investigated as well as its influencing factors. While the actual observation process will be objectively measured using eye-tracking, it will become clear throughout the dissertation that the basic act of visual perception cannot be studied separately from its psychological component. In summary, when we will use the term ‘observation’ or ‘visual perception’, it will refer to the visual mechanical process of perception (whenever eye-tracking is concerned) since this is the focus of the thesis. However, when psychological aspects come into play (whenever observer characteristics are studied), ‘perception’ will be used and must be interpreted in its broader sense, comprising mental processes of interpretation, association and understanding. The following paragraphs provide more information about the physiological and the psychological aspect of perception and what is meant with both terms.

Physiological component of visual perception. When we perceive the environment, a whole system of *senses* is activated, including the sense of hearing, touch, smell, taste and vision (Lange, 2005). From this list, vision is for the vast majority of people by far the most important sense as it accounts for more than 80% of human perception (Shafer, 1969; Bruce et al., 1996; Bell, 2004; Lange, 2005). The physiological aspect of perception – the ability to observe – is thus mainly determined by the eyes and their functioning. In particular, in healthy eyes the visual information from the surrounding environment – i.e. light signals of which the incoming amount is regulated by the iris – enters the eye through the cornea, travels through the pupil and passes through the lens to be projected onto the retina. In the retina, millions of photoreceptors process the incoming visual information and transform it into electrical signals each carrying the details of the visual image. These signals are subsequently transmitted to the back of the brain by the optic nerve, the bundle of all nerve fibres to which each photoreceptor is connected. As the optic nerve of each eye cross each other, the right part of the brain receives information from the left eye and vice versa. The overlap of both fields of vision enable us to perceive depth (stereo vision). Finally, the brain assembles all the information into a complete image and interprets it (Oyster, 1999). Separate but interacting parts of the brain each control different aspects of this final process. While a detailed description of the brain functioning is beyond the scope of this introduction, we can summarize that certain regions of the brain called ‘ventral stream’ are responsible for the recognition and identification of visual stimuli, whereas the ‘dorsal stream’ accounts for the spatial localization and the direction of attention towards objects of interest (see Itti and Koch, 2001 for an extended description). This attention allocation process is influenced by two aspects: bottom-up and top-down factors (Treisman and Gelade, 1980; Bergen and Julesz, 1983; Ulrich, 1983; Nakayama and Mackeben, 1989; Hikosaka et al., 1996; Braun and Julesz, 1998; Matlin, 2009). The bottom-up mechanism is a fast precognitive, low-level mechanism, which guides eye movements according to the features of the image. A location in a scene, which highly differs from its surroundings – mostly in terms of colour, orientation and intensity (i.e. salient location) – will thus catch the attention. In this case, attention deployment is stimulus-driven. It only depends on the instantaneous sensory input (Desimone and Duncan, 1995; Itti and Koch, 2000, 2001; Rajashekar et al., 2008). Bottom-up processes operate automatically in each healthy human being and deployment of attention requires no effort as salient regions draw attention to themselves. Bottom-up attention deployment is therefore called 'involuntary' attention by James (1892) and is labelled as 'fascination' by Kaplan (1995), describing it as attention based on interest. When a scene is fascinating, it will not demand a lot of effort to stay interested and entertained, attention will not drop (Kaplan, 1995). This is not the case for top-down mechanisms of attention deployment (see next paragraph).

The entire process of observation operates continuously over the entire visual field and at multiple spatial and temporal scales (Itti and Koch, 2001). According to Minelli et al. (2014), the static human field of view is approximately 170° in its horizontal component and 135° in the vertical direction, with a binocular view of approximately 120 by 110 degrees (Ware, 2004) (Figure 1.1). However, this can be extended in two ways: the observer can extend his/her sight by 360° on the horizontal plane and the head can be moved in a vertical sense to increase the vertical angle of view. This is called the dynamic field of view (Minelli et al., 2014). All aspects of the physiological observation can be measured objectively. This is what this dissertation aims to achieve through the use of eye-tracking for measuring people's observation of landscape photographs.

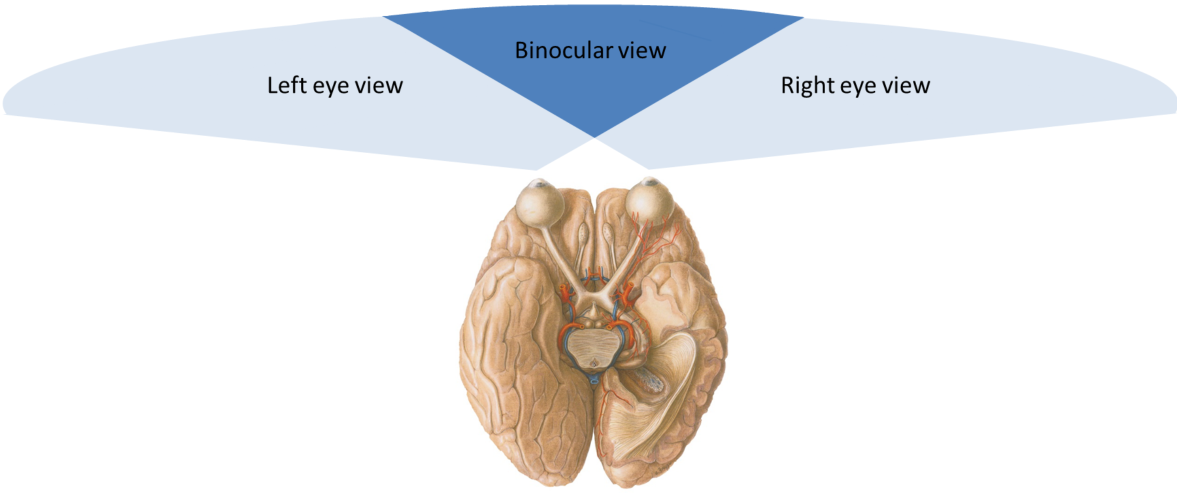


Figure 1.1 Illustration of the human field of view (edited from Putz and Pabst, 2006).

Psychological component of visual perception. Visual perception cannot be investigated thoroughly when the mental processes occurring in each observer during perception are not considered. Instead, researchers should try to take this aspect into account or at least be conscious of the presence of such psychological processes operating in the background as perception and interpretation are inseparable. More specifically, when observing something, the brain automatically interprets and tries to understand what is presented in front of the eyes. A visual stimulus – an object or an environment and its specific characteristics – only gets meaning through association, when the content which is viewed by the eyes is checked against some coherent body of ideas (Meinig, 1979). This is what is called 'concepts' by Jacobs (2006). Concepts are pre-existing mental structures which allow us to recognize things and make sense of them. When looking at a tree, people employ the concept of a tree and indeed recognize the object as being a tree (Jacobs, 2006). According to this, you only *see* what you know or recognize, what can be associated to some extend to the concepts present in the mind (Jacobs, 2006; Sevenant, 2010). These concepts, stored in networks and forming the units of human memory, are acquired throughout life during the process of perceiving (Jacobs, 2006). However, this body of ideas or concepts is distinct in each single individual as it is influenced and shaped by culture, social background, experience, acquired knowledge, mood etc. (Sevenant, 2010; Kaplan, 1988). Such concepts guide attention in a top-down fashion. In this case, attention deployment requires voluntary effort (James, 1892), overruling bottom-up processes of attention allocation. Directing gaze at less salient or non-salient parts of an image can only happen under voluntary effort of the observer (Itti and Koch, 2000). This is, for example, necessary when interest fails. Effort will be required to pay attention to something that is not interesting (Kaplan, 1978).

Perception is thus the result of both the sensory information that is affecting our senses and the pre-existing concepts used in the constructing process (Jacobs, 2006). In the specific case of landscape, this reasoning results in the following interesting statement postulated by Meinig (1979) and reformulated by Sevenant (2010):

"It will soon be apparent that even though we gather together and look in the same direction at the same instant, we will not – we cannot – see the same landscape. We may certainly agree that we will see many of the same elements – houses, roads, trees, hills – in terms of such denotations as number, form, dimension, and colour, but such facts take on meaning only through association. (…) Thus we confront the central problem: any landscape is composed not only of what lies before our eyes but what lies within our heads."

(Meinig, 1979, p1)

"This explains partly why different people looking at the same scene, perceive different shapes and patterns (…)"

(Sevenant, 2010, p48)

It has been mentioned that such differences in perception are the result of different interpretations while the basics of perception, the observation in itself, is the same for all healthy human beings. However, in this dissertation we want to investigate if indeed perception – in the sense of the objective observation – is the same for all people in all situations or if it varies according to specific factors. In particular, we will focus on landscape scenes. While we know that for most of us the mechanical observation – how the eyes function – is identical, much less is known about what exactly we observe or look at in a scene, which details catch our attention and if this is similar for all people in all sorts of scenes. The visual behaviour depends on two main aspects: the characteristics of the visual array (what is presented to the eye, in our study: the landscape, its content and how it is represented) and the functioning of the observer's mind (we only see what we know or recognize, the body of ideas against which everything is checked (Meinig, 1979; Sevenant, 2010)). Variations in these aspects might give rise to different visual observation patterns, which in turn might lead to different interpretations and different mental images of the same (landscape) scene. As observers react to their own mental image of a landscape when forming an opinion about it, differences in visual perception might result in diverging opinions or judgements of/about the same landscape (Unwin, 1975). Investigating the objective observation of landscapes could thus be very beneficial for a better understanding of differences occurring in landscape evaluation. In addition, this kind of research could be relevant for landscape policy since this is often based on the visual aspects of the landscape. For these reasons, the main aim of this study is to investigate how people observe landscapes, how the visual behaviour is characterized, which factors influence this behaviour and where the differences lie.

1.1.2 Factors influencing landscape perception

In accordance with Sevenant (2010) we distinguish three categories of factors which influence landscape perception: the landscape itself, the observer and the practical context. The latter comprises the purpose with which the landscape observation happens, whether landscape observation occurs on site or is based on a landscape representation, which type of stimulus is used, weather conditions etc. In this dissertation, the influence of these three factors on the visual observation are explored. The following paragraphs describe each of these aspects in greater detail.

1.1.2.1 *Practical context*

It might seem strange to start with the practical context, but when setting up a study about landscape observation, one of the first things one has to ask oneself is how the landscape needs to be (re)presented.

A first possibility is to take the participants on site to perceive the real landscape. However, this method is time and money consuming, tough to plan and to organise and the number of visited sites is restricted. In the specific case of studying the visual observation of landscapes, a couple of other issues arise from this approach. Besides the visual sense, other senses might be provoked, for example by noise, smell etc. which may unconsciously influence the visual behaviour. Similarly, the weather conditions might have an impact as well. The contrast between a landscape observation in stormy conditions accompanied by wind and rain or in sunny conditions under a cloudless sky does not need much explanation. The weather conditions will on the one hand influence the (mood of the) observer, who will perhaps adjust the time spent viewing a landscape. On the other hand, the weather and the atmospheric situation will also have an impact on the illumination conditions, which determine the depth of view. In particular, atmospheric attenuation increases with the distance between the observer and the viewed objects until the objects become hazy, fuzzy and bluish and finally fade out (García et al., 2006). Antrop (2007) distinguishes a critical viewing distance, beyond which singular objects cannot be discriminated from the background (usually 1200m), and a theoretical viewing distance which is much greater. These distances, and thus the visibility, increases with increasing illumination (bright weather). Enhanced or hampered visibility will as a consequence also influence the viewing behaviour in landscapes as it determines how far people can actually see in the landscape. Studying landscape observation in situ also encounters other reproducibility problems. Not only weather conditions, noise and smells may vary from one day to another (supposing that not all the participants can be taken on site at the same moment, especially when large groups of participants are needed to assure statistical significance), the presence of people or animals in the landscape may also differ from one observation to another, especially since these have been demonstrated to catch the attention (Buswell, 1935; Yarbus, 1967; Abrams and Christ, 2003; Franconeri and Simons, 2003). The same argument holds true for moving objects of diverse origins (e.g. cars, boats, waving trees, flowing water, windmills, birds, airplanes etc.) (Abrams and Christ, 2003; Franconeri and Simons, 2003). Finally, the purpose with which the landscape is observed might affect the viewing pattern. While in real life landscapes are usually observed without a specific purpose – most commonly for relaxation reasons (e.g. during recreational activities) or during transport (e.g. in a train or car) – a landscape observation performed in the context of a study or survey might be completely different. The most important reason for this discrepancy is the introduction of a task, given to the participants. Multiple eye-tracking studies have revealed a clear difference in viewing behaviour depending on the presence or absence of a task (Yarbus, 1967; Tanenhaus et al., 1995; Andrews and Coppola, 1999; Peebles and Cheng, 2003). More specifically, an increase in cognitive demand (task-related) leads to distinctly different, i.e. more efficient, viewing behaviour with shorter fixations and larger saccades (Kowler et al., 1992; Epelboim et al., 1995). While all these aspects may seem to be minor details, their impact on landscape perception is often mistakenly underestimated (Sevenant, 2010). Most study designs cannot take all these factors into account for technical or practical reasons. However, researchers must at least be aware of the presence of these factors and their potential influence on the results of the study.

As a substitute for in situ investigations concerning landscape perception, researchers often rely on representations of the landscape such as photographs, drawings and computer-aided simulations. An example is given by the innovative technique of the Virtual Landscape Theatre, which is a mobile curved screen projection facility that can be used for simulating the environment and 'immerse' people, developed by The James Hutton Institute (2016). However, by far, landscape photographs are the most used surrogates since different authors (e.g. Shafer and Richards, 1974; Daniel and Boster, 1976; Zube, 1974; Shuttleworth, 1980; Coeterier, 1983; Zube et al., 1987; Sheppard, 1989; Palmer and Hoffman, 2001) have tested and justified their validity for representing the visual landscape. However, Palmer and Hoffman (2001) are concerned that a standard photograph with a limited field of view may not be representative of a whole landscape, which on site can be observed within a much broader angle of view. As a consequence, they advise using more than one photograph from different viewpoints to represent highly diverse landscapes. Nevertheless, we believe that the choice of (re)presentation of the landscape – stimulus or in situ – depends on the purpose of the study. In particular, it will be determined by the question whether the respondent/participant needs to physically 'experience' the landscape in terms which cannot be represented on photographs (e.g. noise, traffic, moving objects etc.) or whether an overall visual image of the landscape is sufficient. The latter is possible when a specific aspect that can be captured in one or more relevant photographs of the landscape, is investigated.

1.1.2.2 Properties of the landscape

As mentioned before, the landscape along with its characteristics is one of the factors influencing visual perception. However, when analysing the relationship between the visual physical features of the landscape and the human observation, one first needs to know which aspects determine the visual character of the landscape – it is this character and its determining factors that will influence the human viewing behaviour – and how these aspects can be quantified or estimated.

Ode et al. (2008) define landscape visual character as "*the visual expression of the spatial elements, structure and pattern in the landscape*". Numerous studies have attempted to describe and analyse this visual character along with the visual quality of the landscape (see Zube et al., 1982 and Lothian, 1999 for an overview). In this context, Tveit et al. (2006) reviewed an extensive body of literature about this topic and elaborated a theoretical framework for visual landscape character assessment based on nine key concepts. In particular, a landscape's visual characteristics can be described by the following concepts: stewardship, coherence, disturbance, historicity, visual scale, imageability, complexity, naturalness and ephemera. *Stewardship* refers to the presence of order and care in a landscape, *coherence* to the unity of a scene in terms of repeating colour or texture patterns, whereas *disturbance* reflects the lack of coherence. *Historicity* relates to the time depth of a landscape and to the amount, condition and variety of cultural items. The *visual scale* of a landscape is defined by its openness and visibility. According to Weinstoerffer and Girardin (2000) and Antrop (2007) openness is defined as the possibility to obtain extensive views over the landscape. *Imageability* can be described as a landscape's ability to create a strong visual image in the observer making it distinguishable and memorable. *Complexity* refers to the diversity and richness of elements and features present in a landscape, a definition which is also used to describe heterogeneity. *Naturalness* is regarded as the degree to which a landscape approaches a natural state. Finally, all elements or features of a landscape which change with season and weather are considered as *ephemera* (Tveit et al., 2006). These concepts should not be considered as independent from each other but rather as a set of minimum overlapping interrelated concepts, which together determine the visual character of a landscape. For each concept Tveit et al. (2006) provide the visual dimension through which it can be expressed as well as the physical landscape attributes contributing to these dimensions and the corresponding visual indicators which can be objectively quantified and mapped. While the framework has been set up to be widely used, it should be mentioned that some of the concepts are context-dependent on the landscape type (e.g. naturalness will be perceived differently in rural and urban settings) whereas others are observer-dependent (e.g. historicity will be perceived differently by a historian than by a biologist). Nevertheless, some concepts are more general and are less affected by external influences of context or observer (e.g. visual scale, complexity) (Tveit et al., 2006).

1.1.2.3 Properties of the observer

The definition of landscape as formulated by the European Council of Europe (2000), touches upon perception and more specifically states that landscape is an area perceived by *people*. Landscape is thus defined from the human viewpoint. Animals perceive the environment too, but their landscape is probably different from ours because of differences in scale (size of the animal in relation to the objects in the landscape), in physiological mechanisms of vision (e.g. colour or non-colour vision, presence or absence of depth vision etc.) etc. (Walk, 1965). This might seem an extreme example but it points to the fact that landscape varies according to whom, in the broadest sense, is perceiving it. This is also the case when it is perceived by different people. According to their background comprising socio-demographic and cultural aspects as well as aspects concerning attitude and values (Sevenant, 2010; Howard, 2013), they might perceive the landscape in a multitude of fashions and from a myriad of viewpoints. Socio-demographic factors such as gender, age, income, economic status, social class etc. have been acknowledged to have an effect on landscape perception. Similarly, the influence of socio-cultural aspects like expertise and prior knowledge, ethnicity, culture, religion, living environment, activity in the landscape etc. has also been demonstrated in literature (Sevenant, 2010; see Howard (2013) for an overview). Finally, the values, beliefs and attitudes of someone towards landscape and one's mental image of nature and view on the world also impacts on one's landscape perception (Buijs et al., 2009).

In this respect, Meinig (1979) explains how a landscape is described completely different according to whom is perceiving it. He distinguishes ten possible views on the landscape: landscape as nature (back to basics), habitat (landscape as a place to live), artefact (landscape as shaped by man), system (landscape as science), problem (landscape as concern, issue), wealth (landscape as monetary value), ideology (landscape as value, culture), history (landscape as a witness of the past), place (landscape as locality with sense of individuality) and aesthetic (landscape as quality of being pleasing) (Meinig, 1979). From this point of view, it is likely that a scientist who approaches landscape as a complex system steered by processes might perceive the landscape quite differently from a historian who is interested in unravelling the past of a place.

Familiarity towards the landscape also affects perception across observers (Kaplan and Kaplan, 1978; Hammitt, 1979; Mancas, 2008; Forsythe, 2009). Mancas (2008) points out that the top-down influence, guided by the cognitive characteristics of the observer

(Rajashekar et al., 2008) and operating during perception is higher when observing a known image. On the contrary, in unknown scenes, the bottom-up mechanisms of attention, steered by the content of the image (Rajashekar et al., 2008), are more dominant. In general terms, we can state that prior knowledge and experience influence visual perception. More specifically, people perceive the environment depending on previous information and past experiences, through which in some cases familiarity with a place arises (Kaplan and Kaplan, 1978). In particular, people develop a cognitive model or mental image of an environment based on former experiences, which in turn is used to observe the same environment again or a different landscape for the first time. In the specific case of familiar places, Lynch (1960) uses the idea of the ‘mental map’ (Downs, and Stea, 1977; Gould and White, 2012), which people seem to have of a known area and which depends on individual experiences and on the features of the area. According to Lynch (1960), the mental map consists of five elements: paths (e.g. routes), edges (interruption of the continuity), districts (similar areas), nodes (e.g. squares and junctions) and landmarks (easily identifiable points of orientation), which according to how they are assimilated by the observer, influence visual environmental perception.

Finally, Kaplan (1988) states that the perceptual process is inextricably connected with human purposes. Since different people may pursue different purposes or change his/her purpose depending on the time and situation, visual perception is quite idiosyncratic. However, in the next sections we will see that human purposes show a certain degree of similarity instead of being completely scattered. In summary, a number of evolutionary processes have shaped the human perceptual mechanisms and reactions in such a way that a kind of basic ‘perceptual instinct’ was formed, which is to a greater or lesser extent active in each human being.

1.2 EVOLUTIONARY THEORIES IN LANDSCAPE PERCEPTION AND EXPERIENCE

Although perception differs from one observer to another, remarkable communalities have been found, probably because of the common evolutionary heritage of humankind (Kaplan, 1988). In this section, a number of theories which relate evolutionary processes to environmental perception are described in order to better understand the human viewing behaviour when observing landscapes. The psychology behind these theories is to some degree present in each human observer and thus, mostly unconsciously, affects or even guides the viewing pattern during environmental perception.

1.2.1 Prospect-Refuge theory and Savannah hypothesis

A first evolutionary theory formulated by Appleton (1975, 1988) suggests that humans perceive the environment in order to maximize survival. In particular, environmental information – in landscapes mostly obtained through sight – is acquired and stored in such a way that a quick and efficient retrieval when needed, is ensured. Two basic principles are important in this process: the opportunity to continuously gain information (mainly through sight) and the possibility to conceal oneself as observer. In other words, 'seeing without being seen'. Human beings will thus seek for places from which a broad view on the surroundings is obtained (prospects) from which possible predators, preys or mates can be identified, while at the same time their safety is guaranteed (refuge). Appleton (1975, 1988) distinguishes four types of prospects: the panorama or wide view, the vista (view which is restricted by horizontal or vertical margins), the secondary panorama (a vantage point elsewhere) and the secondary vista (deflected view). Refuges are classified by function, origin, material or accessibility. An unimpeded range of vision and concealment are directly related to survival. It is thus very probable that people scan an environment in search of such places according to these principles.

According to Orians (1986), the African savannah landscapes, which formed the habitats of our ancestry, come closest to the idea of prospect-refuge. The relatively open grasslands with scattered trees or small groups of trees provide the optimal condition for both prospect and refuge. As these conditions maximize survival, proto-human populations consequently searched for areas that afforded prospect and refuge. Through natural selection, this type of landscape is thought to have become genetically ‘implanted’ in human beings, which would also explain people’s current innate preference for ‘savannah-like’ landscapes or landscapes containing key features of savannah habitats (Orians, 1986). Note that the savannah hypothesis ignores the built structure and other hard surfaces uncontestably part of the contemporary urbanised landscapes, as argued by Lundholm (2006).

1.2.2 Information-processing theory

The Information-processing theory formulated by Kaplan and Kaplan (1995) postulates that humans pursue two basic needs in their environment: understanding and exploration. Understanding refers to the impulse to comprehend what is happening in the immediate here and now, it is related to the structure of the environment. Exploration deals with the need to expand the horizons, to learn and find out more about what is going on in a place. Both needs might be met through observation of what is immediately perceptible in a scene or by moving through the landscape to discover features that were not visible at first sight (inferred perception). The possible combinations of those needs with the levels of information availability generate four ‘informational factors’: complexity, coherence, legibility and mystery (Kaplan and Kaplan, 1995). Complexity refers to a scene’s richness, how much there is to look at, the degree of variety. It is an aspect that influences the immediate exploration: exploration will increase when complexity reaches higher levels. Coherence, or the sense of order and unity in a scene, is related to the immediate understanding of an environment. Higher coherence will enhance understanding. Legibility can be described as the ease with which a landscape can be understood and remembered and the effort it takes to identify the different objects in the environment and orient oneself (e.g. Lynch’s mental map). In other words, the ease with which one can move efficiently through the landscape can be considered as an indicator of legibility. Highly legible landscapes are landscapes in which one can easily find his/her way. Legibility is thus a concept which must be approached not as immediate but as inferred understanding. Mystery involves the promise to learn more about a setting when one would get the opportunity to move further into the scene. It deals with inferred exploration as it refers to information that is not immediately apparent from the first vantage point. The higher the ‘mystery-level’ of a scene, the higher its exploration will be. Finally, it should be noted that both complexity and coherence are relying on the two-dimensional aspect of a setting, while legibility and mystery require the three-dimensional representation of the environment (Kaplan and Kaplan, 1995). Kaplan and Kaplan (1995) conclude by stating that humans unconsciously interpret the environment according to their needs and purposes and thus seek for settings and features which allow an effective functioning.

1.2.3 Model of affective response to natural scenes (Ulrich, 1983)

This psycho-evolutionary model postulates that in environmental encounters feelings come first, followed by cognitive events such as thoughts, which are shaped by affect (Ulrich, 1983). The initial response is guided by a fast bottom-up process of visual perception, while slower top-down activity steers the cognitive processing (see section 1.1.1). According to Ulrich (1983), the initial affective state and reaction of an observer influences the visual perception of natural environments. In particular, the first reaction to a scene is an affective reaction (e.g. like, dislike, interest, fear) based on very little information but necessary to quickly decide whether an environment can be approached or needs to be avoided (Ittelson, 1973; Zajonc, 1980; Ulrich, 1983). While not empirically tested yet, this reaction is believed to influence attention as it helps selecting the features or areas in a scene that are important to perceive in order to quickly adapt or undertake behaviour through eliciting affect (Izard, 1977; Ulrich, 1983). While this initial reaction requires no identification or extensive processing, it influences the ensuing cognitive evaluation of the scene, including recognition, identification and much more extensive processing of the information. This slower cognitive process in turn influences the observer’s affective state as it adjusts, refines or sharpens the initial affect. New or adjusted affect might be reflected in the perceptual activity, cognition and behaviour (Lazarus, 1968; Izard, 1977; Ulrich, 1983). Scenes which elicit an affective reaction of preference are believed to entail an enhanced visual exploration and processing of visual information along with an elaborated cognitive process supporting an exploring behaviour (Ulrich, 1983).

1.2.4 Gestalt theory

Another theory which has been demonstrated to explain human visual perception is the Gestalt-theory and its principles as developed by Köhler (1929; 1947) and Koffka (2013). Briefly summarized, the theory states that people perceive things as a whole or *Gestalt* which has a reality of its own and is independent from its constituent parts. The whole is thus more than the sum of its constituent parts (Antrop, 2000), it takes the relations between these parts into account and is more than a collection of unrelated items. This is also referred to as 'holism' (Smuts, 1926). People perceive visual stimuli as organized or grouped patterns. This organisation is based on the interactions between and relative positions of the elements, which are summarized in a number of Gestalt-principles dealing with similarity, proximity**,** closure, continuity and figure-ground. The principles of proximity and similarity imply that people perceive objects which, respectively, are close to each other or look similar, as a group or pattern (Köhler, 1947). Continuity occurs when the eye is fluently guided from one object to another. Closure can be described as the phenomenon of people filling in the missing information in objects which are incomplete but offer enough shape to be recognized. Finally, the figure-ground principle entails that the human eye differentiates an object from its surrounding area, or a 'figure' from its back'ground' (Köhler, 1947). These principles have been demonstrated to operate unconsciously during human perception processes, including landscape perception as acknowledged by Bell (1999 and 2004) and Antrop (2007).

1.3 LANDSCAPE PERCEPTION IN PLANNING AND DESIGN

While landscape perception is applied in different fields of interest like for example education, arts, psychology, recreation, heritage, archaeology etc. (Zube et al., 1982), it's most direct application lies in the domain of landscape planning and design.

Therefore, we will only discuss the latter topic in more detail in the next sections. The applications proposed in the dissertation will also relate to landscape planning and design. More specifically, the focus will predominantly be on how the visual aspect of the landscape is considered in planning and design procedures. The application of landscape perception findings in landscape planning and design comprises two aspects. First, complex academic knowledge and methods need to be translated into applications which can be used in practice. Second, the legal context needs to be taken into account when doing so (e.g. European Landscape Convention, Convention of Aarhus with respect to public participation for instance). As will become clear from the next sections, these aspects are often difficult to deal with in practice.

1.3.1 Landscape assessments

Landscape management, planning and design, and landscape policy in general, often use landscape character assessments for different purposes (Nijhuis et al., 2011). Such assessments of the landscape involve the inventory and evaluation of the attributes visible in the landscape (Palmer and Hoffman, 2001; Dakin, 2003; Kaymaz Cakci, 2012). In particular, landscape management and planning is inextricably linked with visual perception (Berlan-Darqué et al., 2008) as landscape change essentially affects the visual aspects of the landscape (Dakin, 2003; Gobster et al., 2007). Visual perception can thus be considered as a key factor for landscape planning and design (Nijhuis et al., 2011). Landscape assessments are usually obtained through the use of landscape photographs, which people are asked to rank based on certain aspects (Unwin, 1975; Al-Kodmany, 1999; Palmer and Hoffman, 2001; Tress and Tress, 2002; Bishop and Rohrmann, 2003; Lange, 2005; Ryan, 2006). Photographs provide a strong, clear and efficient visual medium of communication (Tufte, 1992) and are therefore very suitable instruments for informing or involving the lay public (Tress and Tress, 2002; Bishop and Rohrmann, 2003; Ryan, 2006).

Public participation in landscape issues is advocated by the European Landscape Convention (Council of Europe, 2000), and enshrined in its Articles. All citizens should have the right to say in relation to decisions concerning landscapes and their planning and management. Therefore, landscape should not be exclusively destined for scientific research and specialists but instead be the interest of everyone (Council of Europe, 2000). As implicitly suggested in the formal definition of landscape as an area as *perceived by people*, the view of the general public should be consulted and integrated in landscape planning and design (Council of Europe, 2000). Selman (2006) argues that there is an urgent need to incorporate the views of the public into landscape design, management and planning decisions. The benefit is twofold: the sharing of information enhances knowledge and awareness of the public and authorities gain insight into how the landscape and its problems are perceived and experienced by the public. Additionally, incorporating the public's knowledge and point of view in the decision-making process could facilitate and hasten the search for an optimal solution/decision (Jonsson and Lundqvist, 2006). However, in practice this goal has too often been dismissed (Selman, 2006) and landscape assessments have been very top-down driven by experts (Pinto-Correia et al., 2006; Tassinari and Torreggiani, 2006; Kaymaz-Cakci, 2012).

1.3.2 Visual impact assessment

A very specific case of landscape assessment is visual impact assessment. Ideally, the planning process includes a visual impact assessment of the proposed changes. Visualisation is a very valuable instrument for this purpose (Bell, 2001) as it enables the conceptualization of different scenarios of change (Lange, 1994; Pullar and Tidey, 2001). Scenarios are then rated according to expert and/or public appraisal (Palmer and Hoffman, 2001; Tassinari and Torreggiani, 2006). Efforts are made to integrate this approach in the planning process, for example in the UK (e.g. the use of the Virtual Landscape Theatre by The James Hutton Institute, 2016; The Landscape Institute of Environmental Management and Assessment, 2002) and the USA (e.g. US Department of Transportation, 2015; USDI Bureau of Land Management, 1980a and 1980b). However, seldom is the assessment of the visual impact of new projects a compulsory part of the planning process (Lange, 1994; Schmid, 2001). In Flanders, an evaluation of the visual impact of landscape changes is only required when the project is bound by an *Environmental Impact Assessment* (EIA). This is an assessment, mostly only compulsory for very large scale projects such as railways, motorways, airports, dikes, industrial infrastructures, energy parks etc., of the effects that a project could have on the environment. It is performed in advance of the final decision and it comprises the assessment of the changes in structure and relationships in the environment (geomorphological, ecological and functional), loss of heritage values, visual impact and impact on landscape experience (Schute et al., 2006). However, smaller projects are not subject to such assessments and thus, apart from local planning regulations which might be into force, planners and designers have a great deal of freedom. Architectural fragmentation, loss of unity and visually non-integrated constructions are a common result (Tassinari and Torreggiani, 2006). In the few cases when assessed, visual aspects of new projects are too often only considered in a merely non-transparent and intangible fashion, if considered at all (Lange, 1994; Schmid, 2001). One of the reasons for this is the lack of clear, standardized and quantitative methods for estimating the visual impact (Lange et al., 1994; Uzzel and Jones, 2000; Minelli et al., 2014; Palmer, 2015). Although efforts have been made to investigate how to visually integrate agricultural buildings, greenhouses and renewable energy infrastructures (e.g. García et al., 2006; Rogge et al., 2008; Ladenburg, 2009; Minelli et al., 2014), clear uniform visual assessment methods are still missing. In some cases, this results in unrealistic and very expensive methods, applied to simulate the visual effect of planned projects, such as erecting a fullscale model of the construction, simulating the size of the construction by placing pylons or cranes or using air balloons and zeppelins to simulate the height of the construction (Nijhuis et al., 2011). These are exceptional measures, which are mostly intended to evaluate the visibility impact of the construction – how far will it be visible (height, size) – and less on the visual integration of the building – how well does it match with its surroundings (design aspects). While the former aspect is sometimes estimated using GIS-tools (e.g. viewshed analysis) (Nijhuis et al., 2011), especially the latter is rarely assessed. Thus, while there usually is a will in policy makers to limit the visual impact of landscape change, this aspect of landscape planning and design is too often neglected (Dakin, 2003; Gobster et al., 2007).

1.4 EYE-TRACKING AND EYE MOVEMENTS

Since this dissertation focuses on landscape observation, the visual element is crucial. Therefore, eye-tracking is used as a method to reveal how people visually observe landscape photographs. The technique enables to objectively measure which aspects of the landscape catch the attention and how the photographs are visually explored. This section starts with an explanation of the eye-tracking technology, continues by giving an overview of the domains in which it has been applied and concludes with describing how eye-tracking has been used in landscape perception research so far.

1.4.1 Technology

The eye-tracking technique has a long history going back as early as the end of the nineteenth century, when the first eye-trackers were built and the first results were reported (Holmqvist et al., 2011). While the early techniques were quite invasive – for example, the eyeball was anaesthetized using cocaine or contact lenses and mirrors were used (e.g. Delabarre, 1898) – more modern and more comfortable techniques were developed during the twentieth century. Most important is the development of the principle of photographing the reflection of a closely positioned external light source from the cornea of the eye, a video-based technique which has become the most widespread one for measuring eye movements today (Duchowski, 2007; Holmqvist et al., 2011). More specifically, a low power infrared light is sent into the eye(s) to be reflected by the cornea and the retina. This reflection illuminates the internal eye, which in turn makes it possible to identify the centre of the pupil and locate the corneal reflection. When calculating the vector between both, the position of the point of gaze in terms of an x,y-coordinate is obtained after calibration (Jacob and Karn, 2003; Poole and Ball, 2005). From these ‘raw data’, which are difficult to interpret without further analysis (Duchowski, 2007), two basic metrics can be derived from which the viewing pattern of the observer can be described: fixations and saccades. Fixations refer to the moments when the eyes remain still over a period of time, ranging from a few tens of milliseconds up to several seconds (Holmqvist et al., 2011). Typically, the lower time threshold is set at 100-200 milliseconds (Jacob and Karn, 2003). The spatial threshold for defining fixations (maximum separation that data samples can have in order to be considered as one fixation) is also lacking a formal standard but it is mostly set at 0.5°-1° of visual angle if the distance from eye to screen is known (Salvucci and Goldberg, 2000; Holmqvist et al., 2011). Saccades are rapid re-orienting eye movements, which interconnect two subsequent fixations (Jacob and Karn, 2003; Poole and Ball, 2005; Holmqvist et al., 2011). Fixations and saccades are most often extracted from the 'raw data' using a fixation detection algorithm available in eye-tracking software provided by most eye-tracker manufacturers. These algorithms are either based on eye position or on eye velocity (Jacob and Karn, 2003). However, there is no standard technique, nor a standard minimum duration or spatial threshold for detecting fixations (Inhoff and Radach, 1998; Jacob and Karn, 2003). Only guidelines and most used thresholds are available, like the one suggested by Jacob and Karn (2003) (100-200 milliseconds) and Inhoff and Radach's (1998) lower time threshold of 100 milliseconds (as will be used in this study). This lack of standardisation is problematic since small changes in the parameters defining a fixation have been found to lead to considerably different results (Karsh and Breitenbach, 1983). As a consequence, studies in which fixations are defined differently cannot be compared (Jacob and Karn, 2003). Another important parameter in eye-tracking is the sampling rate or the number of measurements of the gaze direction per second. Sampling rates can vary from 25Hz to 2000Hz according to the system used. The choice of sampling rate depends on the nature of the study and thus on the required level of detail of the measurements. Sampling rate affects the measurement of fixation duration, saccade velocity and acceleration. Lower sampling rates increase the risk of sampling errors and thus generate less accurate data (Holmqvist et al., 2011).

1.4.2 Eye movements and attention: what do eye-tracking metrics reveal?

Fixations provide insight into someone's attention deployment and information pick-up from a given scene, since fixations are related to encoding (Poole and Ball, 2005). In particular, the number of fixations produced on a certain object or in specific 'areas of interest' indicates the importance and/or noticeability of that object or area (Jacob and Karn, 2003; Poole and Ball, 2005). *Areas of interest* (AOI) are parts of a display, which are of specific interest to the research and which have been delineated by the researchers in order to analyse the eye movements falling within the area (Jacob and Karn, 2003). Other eye-tracking metrics, which indicate the same aspect (importance/noticeability) are: time to first fixation on-target ('entry time', 'duration before'), percentage of participants fixating the object/AOI, number of visits to the AOI, percentage of time spent on an object/AOI etc. The fixation duration is linked to the processing time necessary to extract information from and interpret a fixated target (Jacob and Karn, 2003; Poole and Ball, 2005). Therefore, long fixation durations are indicative of a person's difficulty extracting information from a display (Fitts et al., 1950; Just and Carpenter, 1976; Goldberg and Kotval, 1998). Long fixation durations could also reflect the preference of the observer for the fixated object. Unlike fixations, visual processing is suppressed during *saccades*, people are thus blind during fast eye movements (Poole and Ball, 2005; Holmqvist et al., 2011). However, saccades provide useful information with respect to the search pattern. According to Goldberg and Kotval (1999) more saccades indicate more searching. Larger saccades reveal the presence of more meaningful cues, which are able to draw the attention from a larger distance (Goldberg et al., 2002). Finally, based on fixations and saccades, the entire *scan path* can be reconstructed and analysed. Derived metrics are the scan path duration, length, coverage calculated with convex hull area etc., which are all indicative of the scanning extent (Poole and Ball, 2005). All the aforementioned metrics can be analysed quantitatively, for example by submitting them to statistical tests. As eye movements have been demonstrated to be tightly coupled to attention (Hoffman and Subramaniam, 1995; Deubel and Schneider, 1996), eye-tracking allows us to objectively measure attention deployment. A qualitative method for analysing this is through the use of so called *attention maps*, which are intuitive representations of the spatial distribution of eye movements and which are easy to understand (Holmqvist et al., 2011). Examples are given by heat maps, multi-coloured representations of the centres of attention, as introduced by Wooding (2002) and luminance maps, in which the luminance of the image is altered according to the distribution of attention (Pomplun et al., 1996). Related to attention maps are *scan path visualisations*, which are visualisations of the sequence of fixations and saccades onto the image (Holmqvist et al., 2011).

1.4.3 Contemporary eye-tracking systems

Currently, experimenters have the choice between two types of video-based eye-tracking systems. The first group are the table-mounted or static eye-trackers, which are put in front of the observer. Some of these eye-trackers, use a forehead and chin rest to restrict the head movements of the participant (tower-mounted eye-trackers), while others leave the observer's head free within a certain volume of space (remote eye-trackers, as will be used in this study). The visual stimuli are presented on a monitor. Remote eye-tracking systems are attached beneath this monitor or can be used in a stand-alone set-up, which allows using projections on a wall. Head-restricted eye-tracking has been demonstrated to achieve higher precisions, which is required for reading tasks for example (Duchowski, 2007; Holmqvist et al., 2011). Remote eye-trackers provide higher comfort to the participants and are easy to use, but the data quality is slightly poorer (Holmqvist et al., 2011).

Besides table-mounted eye-trackers, the eye-tracker device can also be mounted onto the head of the observer (head-mounted eye-trackers). This system comes in multiple varieties: on a helmet, a cap or in a pair of glasses. Unlike the table-mounted trackers, this type of eye-tracker is equipped with a scene camera for recording the stimulus (video of the view). The advantage of this set-up is the almost complete freedom of movement of the observer and the possibility to track eye movements during real life activities. Additionally, a head-tracker can be mounted onto the eye-tracker to enable the calculation of the position of the head in space (Holmqvist et al., 2011). However, this type of eye-tracker has a number of disadvantages such as the lower accuracy of the measurements, the time consuming data processing, the uncontrolled circumstances of testing on-site etc. (see section 7.4.1.3 in the General discussion for a detailed description). For these reasons, table-mounted eye-tracking was preferred over mobile eye-tracking in our studies.

We refer to Holmqvist et al. (2011) and Duchowski (2007) for a detailed overview of the technical possibilities and shortcomings of the different types of eye-tracking systems available today.

Besides these basic categories of eye-tracking devices ongoing efforts are made to produce very accessible, low-cost and smaller eye-trackers (e.g. Eye Tribe Tracker Pro), which can even be integrated into consumer devices such as laptops and tablets (e.g. Tobii EyeX). However, their accuracy and utility, especially for scientific research, remains highly uncertain and needs further investigation and development (Holmqvist et al., 2011).

1.4.4 Domains of application

Jacob and Karn (2003) point out that for a very long period of time (over 50 years) eye-tracking has been classified as a ‘promising’ tool. Since it is still not discarded, it must indeed carry something useful and promising. On the other hand, something must have slowed down its rise and development. Possible factors are the time-consuming and intensive data processing, technical problems, high cost and difficulties in data interpretation. However, today, eye-tracking has become much more user-friendly and reliable (Jacob and Karn, 2003). As a consequence, it has become more and more integrated in diverging fields of interest and eye-tracker devices are available through different manufacturers. The user community has grown from an almost purely scientific customer group to a diversity of users active in a wide range of applied domains. Examples are given by merchandisers and advertisement consultants, who are interested in knowing the effect of advertisement campaigns in and outside the store (e.g. Burke and Leykin, 2014; Huddleston et al., 2015) or on websites (e.g. Shi et al., 2013); sport sciences (e.g. Schorer et al., 2013; Rienhoff et al., 2015); clinical researchers, especially considering eye diseases and disorders (e.g. Kumar et al., 2016) but also health in general (e.g. Jansson et al., 2014; Via et al., 2015), users of gaze-guided computer interfaces, who only have their eyes to operate systems because of diseases or disabilities (e.g. Majaranta and Bulling, 2014; Zhao et al., 2015) etc. (Holmqvist et al., 2011). In fundamental scientific research eye-tracking has been used in fields as diverging as psychology, (e.g. Liu, 2014; Everaert and Koster, 2015) environmental psychology (e.g. Nordh, 2012; Gidlof et al., 2013; Mazman and Altun, 2013), cartography (Kiefer et al., 2014; Ooms et al.,2014, 2015), mobility (e.g. Antonson) etc.

1.4.5 Eye-tracking in landscape perception research

In the domain of landscape perception, eye-tracking has been applied only sporadically in the past. In addition, it was only recently introduced in this research field. De Lucio et al. (1996), for example, investigated patterns of visual exploration in a natural landscape in Spain. Therefore, one landscape photograph was shown to a number of participants. Differences in scanning strategies were found between women and men, with women using more systematic visual inspection strategy while men were rather focusing on specific parts of the scene. However, the results could not be generalized because of the low number of participants (17) and the fact that only a single photograph was investigated (De Lucio et al., 1996). Other relevant research in this field was conducted by Berto et al. (2008), who analysed differences in viewing behaviour in natural scenes high on fascination and low on fascination (see section 1.1.1). Low fascination scenes were found to elicit greater visual exploration than scenes high in fascination (Berto et al., 2008). While this study uses a larger number of photographs (50) the number of participants is still limited (9).

More recently, eye-tracking became more embedded within landscape related research and studies became more elaborate, statistically more reliable and results more generalizable. Examples are the studies of Ode Sang et al. (2014), Pihel et al. (2014, 2015), Cottet et al. (2015), Antonson et al. (2014) and Ren and Kang (2015). Ode Sang et al. (2014) use eye-tracking to analyse which elements in the landscape are of interest when participants (19) are asked how closely images (20) correspond to pasture. Pihel et al. (2014) analyse if assessments of species richness and stewardship differ when evaluated based on landscape photographs or on digitally created landscape visualisations and how eye movements can reveal and explain these possible differences. To this end, 6 photographs and 6 visualisations were assessed by 22 participants. Another recent study tests whether expertise in biodiversity affects biodiversity ratings and the accompanying viewing behaviour when assessing images (23) of recently logged forests (Pihel et al., 2015). The participants of this study comprised 16 experts and 20 novices. Cottet et al. (2015) use mobile eye-tracking to analyse on which basis, in terms of landscape elements, participants (47) assess landscape quality when walking along a partially restored waterway. A more applied study is the research conducted by Antonson et al. (2014), who investigate how different types of objects in the landscape, ranging from modern wind turbines to 19th century churches, influence driving behaviour. Eighteen participants were monitored for their heart rate, viewing pattern and driving behaviour while driving a car in a driving simulator. Finally, Ren and Kang (2015) examine the influence of sound (artificial and natural) on the visual attention pattern while assessing the tranquillity of a landscape. As becomes clear from the brief descriptions of these studies, a more elevated number of participants and stimuli are used compared to the earlier landscape-related eye-tracking studies. This trend predominantly emerged from the need to increase the power and generalizability of the results: more participants and more stimuli generate more data, which makes quantitative statistical analyses meaningful (e.g. ANOVA, t-test, linear mixed-effect model etc.), and in turn offer more solid grounds for a generalisation of the results.

1.5 RESEARCH MOTIVATION AND OBJECTIVES

1.5.1 Research motivation

While all studies mentioned in the previous section use eye-tracking, they are each focused on one specific aspect of landscape perception. The utility of eye-tracking for the broad field of landscape perception has not been thoroughly investigated. The principal gaps of relevance to the overall aim of this thesis relate to the roles that the landscape, the observer and the practical context (see section 1.1.2) play in determining eye movements. This dissertation attempts to fill this gap as it aims at exploring the effects of these three aspects on the viewing pattern made while observing landscapes. In particular, we investigate if and how the landscape characteristics, the practical circumstances and the characteristics of the observer affect the viewing pattern. To this end, eye-tracking experiments are set up in which participants are asked to free-view landscape photographs. Throughout the different experiments, photograph characteristics, landscape characteristics and observer characteristics were varied to analyse their respective effect on the viewing behaviour. The tests were conducted using a table-mounted eye-tracker since the aim of the research is to investigate how people observe landscapes represented on photographs. Free-viewing was chosen to reproduce the usual viewing conditions when people perceive landscapes as close as possible, i.e. without a task in mind. During the experiments, eye-tracking metrics were recorded which were statistically analysed by detecting significant differences between groups formed based on photograph properties, landscape characteristics or observer background. These potentially influencing factors need to be understood before eye-tracking can be fully and reliably applied in landscape research. More specifically, more should be known about which parameters have a high probability of affecting eye movements, produced when observing landscapes or representations of landscapes. Researchers, who are ignorant about possible influencing factors, could, for example, draw erroneous or incomplete conclusions concerning the viewing behaviour. Once more knowledge about these factors is acquired, it will become easier to control for these effects by keeping certain parameters constant, or to eliminate them. If this is not possible for some reason, we believe that researchers should at least have a notion of the aspects that could significantly affect the outcome of their eye-tracking study on landscape perception.

Besides the contribution that the presented work is for science, it can also provide valuable insights, useful for landscape planners and designers. In this field, questions of quality perception and landscape assessments are very important (De Lucio et al., 1996).

1.5.2 Research objectives and questions

The general aim of this dissertation is to analyse how people observe landscapes represented on photographs. This is achieved by using the eye-tracking technology as a means of objectively measuring and analysing the viewing pattern made while observing landscape images. In particular, we are interested in exploring which aspects influence the viewing behaviour occurring when people look at landscapes. Three main factors are believed to influence landscape perception and experience in general: the landscape itself, the observer and the practical context (Sevenant et al., 2010). It is not our purpose to investigate each possible aspect of each of these factors in detail since that would be impossible to achieve within the time frame of this PhD. Instead, we selected a limited number of specific characteristics of the landscape, observer and practical context, which are important for two reasons: they have been given much attention in earlier landscape-related research (not necessarily related to perception) and are relevant in the landscape planning domain. A third aspect which affected our choices and decisions, were practical issues which could not always be solved and which, in consequence, have determined the limitations of this study. In the dissertation, four main research questions, each condensed into specific research objectives, are answered and addressed. In the next paragraphs each research question and its corresponding research objective(s) are described along with a motivation of the choices made.

General research question: How do people observe landscapes represented on photographs?

RQ1: Do the photograph properties, as a specific practical factor, influence the observation of landscape photographs?

RO1: Investigating if and how the view angles of the photographs influence the viewing pattern in landscape photographs.

Amongst other practical factors, we decided to investigate the effect of the type of landscape representation on the viewing behaviour. Landscape can be represented in many different fashions including drawings, sketches, paintings, photographs, desktop-generated visualisations etc. We decided to use landscape photographs in our experiments for several reasons. As mentioned before, landscape photographs have been demonstrated to be valid surrogates for real landscapes (see section 1.1.2.1 for references), which is not or less the case for the other types of stimuli (e.g. Pihel et al., 2014). As a consequence, photographs are by far the most used instrument to study landscape perception and experience when in situ observations are not feasible. However, Palmer and Hoffman (2001) argue that the format of the photograph could affect the results since standard photographs are not able to capture the broad field of view of the landscape as it would be perceived on site. Using panoramic photographs or multiple standard photographs taken from different view point are suggested as alternative solution. Sevenant (2011) indeed found different results of landscape assessments when performed based on standard or panoramic photographs. For these reasons, we decided to test landscape photographs differing in horizontal and vertical angles of view in an eye-tracking experiment to check whether this property could have an influence on the viewing pattern. This is an important first step in establishing guidelines for using eye-tracking in landscape research. In particular, if the viewing behaviour in different landscapes are to be compared, researchers need to know more about the potential effects of differences in view angles of the photographs.

RQ2: Do the landscape characteristics affect the observation of landscape photographs?

RO2a: Investigating the effect of the degree of openness of the landscape on the viewing pattern.

RO2b: Investigating the influence of the degree of heterogeneity of the landscape on the viewing pattern.

RO2c: Investigating how the observation of landscape photographs is influenced by the level of urbanisation of the landscape.

RO2d: Determining if differences in viewing pattern elicited by the degree of urbanisation are related to differences in the visual complexity of the landscape photographs.

Three landscape characteristics are evaluated to answer research question 2: the openness of the landscape, the heterogeneity of the landscape and the level of urbanisation of the landscape related to the visual complexity of the landscape photograph. Openness is considered as the opportunity to obtain extensive views over the landscape (Weinstoerffer and Girardin, 2000; Antrop, 2007). Heterogeneity refers to the richness and diversity of elements in the landscape (Kaplan and Kaplan, 1989; Tveit et al., 2006; Ode et al., 2010), and is highly similar to complexity. As such, heterogeneity and complexity are approached as equivalent variables throughout this dissertation. Openness, heterogeneity and urbanisation/visual complexity were chosen, first because they have been identified amongst others as key concepts for determining the visual landscape character by Tveit et al. (2006) and quality (Litton, 1972; Herzog, 1987; Kaplan and Kaplan, 1995; Coeterier, 1996) and are often used as criteria for visual landscape classifications and assessments (e.g. Meeus, 1995; Bell, 1999; Dramstad et al., 2006). Nijhuis et al. (2011) also state that visual landscape attributes such as the degree of openness and the building density (degree of urbanisation) are important elements in landscape perception and preference. Gaining insight into differences in viewing behaviour in landscapes varying in degree of openness, heterogeneity and urbanisation/visual complexity could learn a lot about how landscape assessments are made, on which aspects/elements of the landscape they are based and what contributed to the decision. As eye movements reveal a lot about which information is extracted from a scene, how easily this happens, how well the scene is understood etc., they provide valuable knowledge which could help explain why certain assessments are made. A second reason for choosing openness, heterogeneity and urbanisation/visual landscape complexity is that these variables are easy to assess or quantify, either by the participants of our studies through sorting tasks (as was the case for openness, heterogeneity and urbanisation level), either by using objective quantification methods based on mathematical calculations (as was the case for the visual landscape complexity).

RQ3: What is the influence of the observer's characteristics on the observation of landscape photographs?

RO3a: Investigating if and how landscape-related expertise affects landscape observation.

RO3b: Determining on which type of features in the landscape experts and laymen spend most attention.

As mentioned before, the characteristics of the observer influence landscape perception and experience. We have seen that these characteristics comprise a lot of aspects such as the observer's gender, age, income, expertise and prior knowledge, ethnicity, living environment, values, attitude etc. In the presented work one specific observer characteristic has been tested: the level of expertise in landscape related matters. We particularly chose this aspect because it has a high degree of relevance in landscape policy and decision-making. More specifically, landscape photographs or simulations are very often used in landscape management and development to probe people's opinion about planned changes (e.g. Sheppard and Meitner, 2005; Dandy and Van Der Wal, 2011; de Vries et al., 2012;). Very often, the visual evaluation of landscape changes of experts, who usually outline the strategies to follow, and the public are discordant (Godschalk and Paterson, 1999; Bell, 2001). We believe that this could be related to the way in which both groups literally observe the landscape. Perhaps, expertise causes people to see different landscape elements, on the basis of which they form their judgement. A comparative study of the viewing behaviour in landscape photographs of landscape experts and lay people could thus be useful in explaining or even partially resolving these opposed judgements. Specifically, we analyse whether there are differences in the general viewing behaviour between landscape experts (i.e. landscape researchers, landscape ecologists, landscape architects and planners, master students with a specialisation in landscape research) and lay people by studying how the landscape photographs are scanned by both groups (RO3a). Subsequently, we investigate on which type of elements in the landscape each group focuses attention and thus which landscape feature is expected to be most meaningful to landscape experts and to laymen.

RQ 4: Can eye-tracking related tools be useful for landscape planning and design?

RO4a: Investigating the reliability of saliency maps as predictions of the human viewing pattern in landscape photographs.

RO4b: Determining the validity of saliency based visual impact assessment as a method for evaluating the visual integration of new constructions in the landscape.

As we have seen, visual impact assessment is given little attention in planning processes, principally as a consequence of the lack of objective methods to measure the visual effects of a proposed plan. When performed, such assessments are mostly based on landscape photographs in which different scenarios are simulated (Al-Kodmany, 1999; Palmer and Hoffman, 2001; Tress and Tress, 2002; Bishop and Rohrmann, 2003; Lange, 2005; Ryan, 2006). As people's opinion about the visual impact of a particular feature in the landscape, i.e. the planned construction, is probed, the eye movement pattern will reveal much about the judgement formulated by the individual. In particular, the viewing pattern will allow to identify which aspects of the landscape caught the attention and which did not or less. As an object's visual impact is related to its visual perception – visual impact decreases when the visual perception is reduced (Hernández et al., 2004) – it is thus possible to deduce the visual impact of an object from people's viewing pattern. In 1996, De Lucio already mentioned the potential of eye-tracking for landscape planning when used in combination with landscape scenario simulations. The fundamental observation pattern could help explain or even predict the responses to alternative designs of planned constructions (De Lucio, 1996). Research question four is related to the question whether eye-tracking derived products can be used for landscape planning and design purposes. In particular, we investigate if saliency maps, which are computationally generated predictions of the human viewing pattern in free-viewing conditions calculated purely on the stimulus content (Parkhurst et al., 2002; Peters et al., 2005; Foulsham and Underwood, 2008), match with focus maps obtained from human observers when viewing landscape photographs. If this is the case, saliency maps of landscape photographs in which new constructions are simulated, could be used to predict its visual impact/visual integration. In particular, we propose a saliency based method for visual impact assessment. In the last research objective, this method is applied to a number of photograph simulations and the outcome is compared to human assessments of the visual integration. As such, the method's applicability and validity are determined.

1.5.3 Dissertation outline

The research questions are addressed in one of the following chapters. The chapters in Part II deal with the analysis of the three influencing factors: photograph properties (Chapter 2), landscape characteristics (Chapter 2 and 3) and the observer characteristics (Chapter 4). The influence of the landscape characteristics is discussed in two chapters as this topic has been investigated together with the photograph properties and the results have been described in the same journal article. Since this dissertation is structured according to the articles, which have been integrally included in the thesis, research question 2 is dealt with in Chapter 2 and 3. Part III consists of two chapters describing possible applications in landscape planning and design (Chapter 5 and 6). In the following paragraphs the content of each chapter will be outlined. Chapters 2-6 correspond to scientific articles which have been published in or submitted to international peer-reviewed journals (see list of publications). Each article included in this dissertation will be preceded by the label ‘modified from’. This modification only refers to lay-out aspects (numbering, font, positioning of figures and tables). None of the content has been changed or deleted. Only in the first article (Chapter 2) footnotes were added on pages 75, 78, 79, 83 and 84 to make a clear reference to the General Discussion, in which a nuance concerning the statistics and interpretations are explained. This is necessary in order to avoid confusion about the different statistical tests and interpretations used throughout the dissertation. Figure 1.2 provides an overview of the structure of the dissertation.

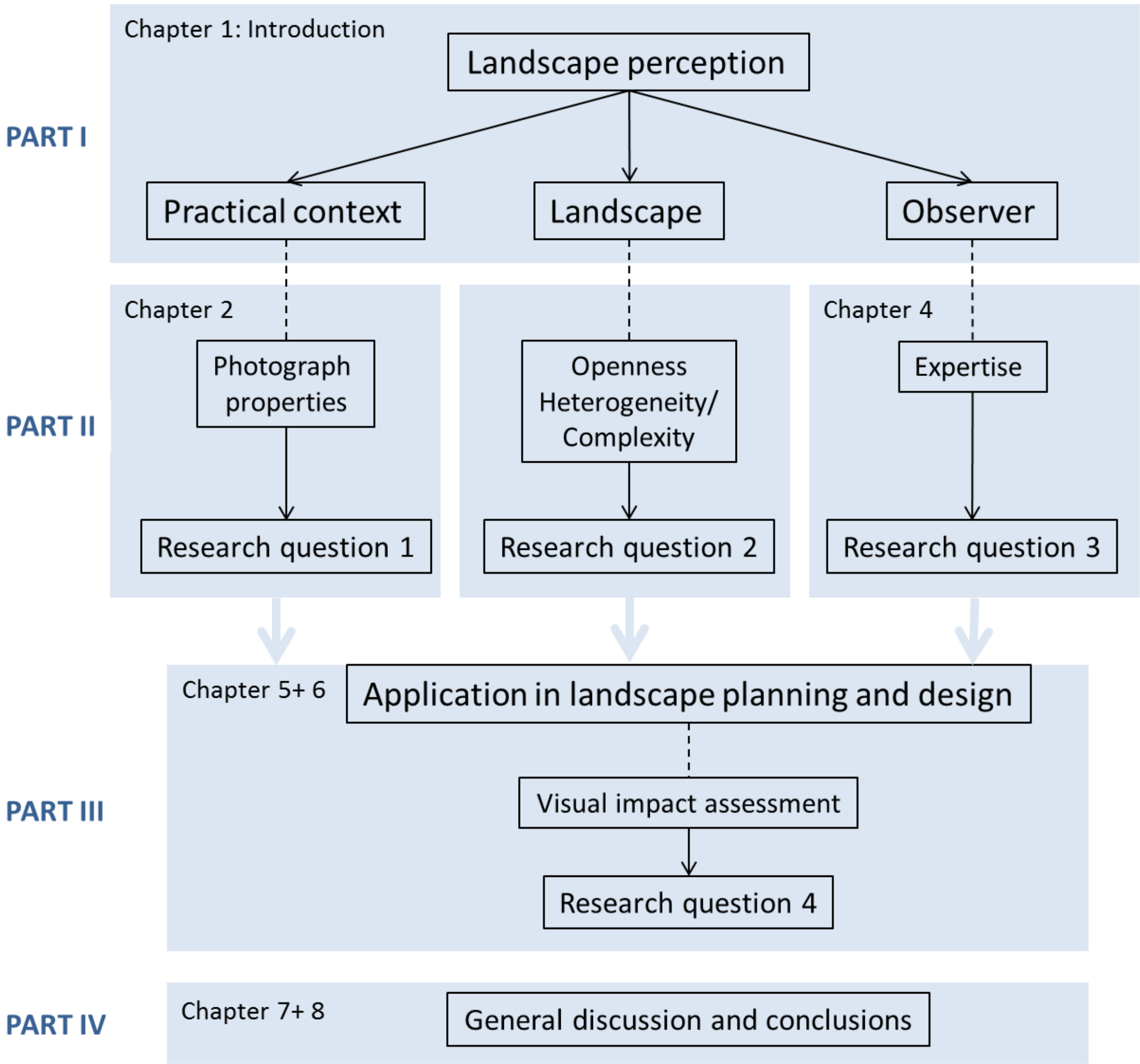


Figure 1.2 Overview of the dissertation outline.

The vast majority of the work presented in this dissertation has been done by Lien Dupont. This comprises photograph sampling, setting up the eye-tracking experiments and photo-questionnaire, gathering and processing the eye-tracking data and the data obtained from the photo-questionnaire, interpreting the results, writing the articles and handling the revisions of the articles until publication. The co-authors of the articles assisted during this process by giving advice. The spectral entropy calculations were executed by Prof. Dr. Andrew Duchowski. Additional software for analysing the eye-tracking data was provided by Dr. Kristien Ooms. The entire dissertation was written by Lien Dupont.

PART II: INFLUENCE OF THE PRACTICAL CONTEXT, LANDSCAPE CHARACTERISTICS AND OBSERVER CHARACTERISTICS ON THE OBSERVATION OF LANDSCAPE PHOTOGRAPHS

Chapter 2: Eye-tracking analysis in landscape perception research: Influence of photograph properties and landscape characteristics (RQ1: RO1 + RQ2: RO2a and 2b)

The first chapter of Part II, published in *Landscape Research* (Dupont et al., 2014) addresses research objective 1 and research objectives 2a and 2b. It describes an eye-tracking experiment which was set up to examine the influence of the photograph properties and landscape characteristics on the viewing behaviour. In particular, landscape photographs with different vertical and horizontal view angles are tested. The represented landscapes varied in degree of openness and heterogeneity. A distinction was made between open, semi-open and enclosed landscapes and between homogeneous and heterogeneous landscapes. These categories were obtained from a photograph sorting performed by the participants. Of each landscape a panoramic photograph, standard photograph, detailed zoom photograph, a more detailed zoom photograph and a wide angle photograph were shown. Eye-tracking metrics such as the number of fixations, fixation duration, number of saccades, saccade amplitude, saccade velocity and observed horizontal and vertical area were measured and statistically analysed in order to investigate the viewing pattern in relation to the factors of interest.

Chapter 3: Investigating the visual exploration of the rural-urban gradient using eye-tracking (RQ2: RO2c and 2d)

The second chapter of Part II discusses how the level of urbanisation of the landscape influences the observation pattern. A number of landscape photographs differing in degree of urbanisation were sorted by the participants of the experiment into rural, semi-rural, mixed, semi-urban and urban landscapes. This classification was validated by calculating the percentage of urbanised area in each photograph. The viewing behaviour in the five categories was compared by performing statistical analyses onto the following eye-tracking metrics: number of fixations, number of saccades, scan path length, observed vertical area and Voronoi cell area (a derived eye-tracking metric indicating the degree of clustering of the fixations). Additionally, the urbanisation level could be linked with the visual complexity of the landscape photographs, as quantified by the spectral entropy of the images. This metric has been introduced as a measure of complexity by Zaccarelli et al. (2013) and can be described as the entropy of the frequency distribution of the photograph. Thus it is based on the pixel values of the image (Ellerkmann et al., 2004; Vanluchene et al., 2004). As such, it takes the diversity or variation of the image into account. As a consequence, the related analysis is a continuation of the previous subchapter in which the landscape heterogeneity was investigated. Heterogeneity and complexity are two very closely related concepts, which both express the diversity or richness of elements and features present in the landscape (Tveit et al., 2006; Ode et al., 2010). In addition, heterogeneity indices have been identified as indicators of landscape complexity (Ode et al., 2008). By linking visual landscape complexity to the level of urbanisation, more information as to why differences in urbanisation level elicit different viewing patterns could be gained. The results of this study have been summarized in an article which is has been accepted for publication in *Spatial Cognition and Computation. An Interdisciplinary Journal.* (Dupont et al., 2016a).

Chapter 4: Does landscape related expertise influence the visual perception of landscape photographs? Implications for participatory landscape planning and management (RQ3: RO3a and 3b)

A third and last aspect which could affect the viewing pattern in landscape photographs tested in this dissertation, is the observer and his/her characteristics and more specifically his/her level of expertise. This chapter, published in *Landscape and Urban Planning* (Dupont et al., 2015), elucidates the results of an eye-tracking experiment, in which the eye movements of a group of landscape experts and a group of laymen were compared. The number of fixations, fixation duration, number of saccades, saccade amplitude, scan path length and Voronoi cell area are recorded for both groups and analyses through statistics. In addition, the objects to which both groups are allocating most attention are qualitatively and quantitatively analysed.

PART III: APPLICATION IN LANDSCAPE PLANNING AND DESIGN

Chapter 5: Comparing saliency maps and eye-tracking focus maps: The potential use in visual impact assessment based on landscape photographs (RQ 4: RO4a)

In the first chapter of Part III, we establish the link between eye-tracking and landscape planning and design, and more specifically visual impact assessment. This has been summarized in an article which has been published in *Landscape and Urban Planning* (Dupont et al., 2016b). In this article, we examine the reliability and potential usefulness of saliency maps to evaluate the visual impact of specific objects in a landscape. The reliability is estimated by calculating the correlation between the saliency maps and the focus maps obtained from real observers to verify whether saliency maps can be considered as reliable predictions of the human viewing pattern in landscape photographs. A method for using saliency maps in visual impact assessment is presented. More specifically, a method to objectively quantify the visual impact/visual integration of different design scenarios of new constructions is proposed.

Chapter 6: Testing the validity of a saliency-based method for visual assessment of constructions in the landscape (RQ 4: RO4b)

The second chapter of Part III comprises an article, submitted to *Landscape and Urban Planning* (Dupont et al., 2016c), in which the method for visual impact assessment described in the previous article is validated by applying it to a number of landscape simulations and comparing the results with assessments made by a number of respondents based on an extensive photo-questionnaire. Landscape simulations depicting different scenarios of a construction (buildings, towers and masts), varying in colour, size or design, were prepared and used in the study. Statistical tests were used to check if the saliency based visual impact assessment method is able to discriminate between different scenario simulations. A correlation between the results obtained from the method and the judgments of the respondents of the photo-questionnaire was performed to analyse the method's validity.

PART IV: GENERAL DISCUSSION AND CONCLUSIONS

Chapter 7: General discussion

Chapter 7 consists of a general discussion of the results presented in the previous chapters. The results of the different studies are interpreted and placed in a broader context. In addition, a critical reflection is made on the methods used in the several experiments and potential suggestions for further research are discussed.

Chapter 8: General conclusion

Finally, Chapter 8 synthesizes the main conclusions of the work presented in this dissertation by formulating answers to the research questions.

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PART II

INFLUENCE OF THE PRACTICAL CONTEXT, LANDSCAPE CHARACTERISTICS AND OBSERVER CHARACTERISTICS ON THE OBSERVATION OF LANDSCAPE PHOTOGRAPHS

<u>CHAPTER 2: EYE-TRACKING ANALYSIS IN LANDSCAPE PERCEPTION RESEARCH: INFLUENCE OF PHOTOGRAPH PROPERTIES AND LANDSCAPE CHARACTERISTICS</u>

Modified from:

Dupont, L., Antrop, M., Van Eetvelde, V. (2014). Eye-tracking analysis in landscape perception research: Influence of photograph properties and landscape characteristics. Landscape Research, 39(4), 417-432.

ABSTRACT The European Landscape Convention emphasises the need for public participation in landscape planning and management. This demands understanding of how people perceive and observe landscapes. This can objectively be measured using eye-tracking, a system recording eye movements and fixations while observing images. In this study, 23 participants were asked to observe 90 landscape photographs, representing 18 landscape character types in Flanders (Belgium) differing in degree of openness and heterogeneity. For each landscape, five types of photographs were shown, varying in view angle. This experiment design allowed testing the effect of the landscape characteristics and photograph types on the observation pattern, measured by Eye-tracking Metrics (ETM). The results show that panoramic and detail photographs are observed differently than the other types. The degree of openness and heterogeneity also seems to exert a significant influence on the observation of the landscape.

KEYWORDS: visual landscape observation, eye-tracking metrics, view angles, openness, heterogeneity

2.1 INTRODUCTION

Landscape perception research became increasingly popular in recent years. This is partially stimulated by new international and formal definitions of landscape, like formulated by the European Landscape Convention: "Landscape is an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" (Council of Europe, 2000). According to this definition, people are put in the core of the landscape and are even part of it while observing the landscape. Furthermore, the Convention states that landscape is an important public interest which constitutes a considerable part of the quality of life for people everywhere. Consequently, an active participation of the public in landscape planning and management is strongly stimulated, for example, by the formulation of the public's aspirations with regard to landscape features of their surroundings by the competent authorities (Council of Europe, 2000).

Considering these statements, it is important to gain insights into people's observation and perception of landscapes to include this knowledge into landscape planning and management. So far, different landscape perception paradigms have been formulated (Scott and Benson, 2002) and analysed using questionnaires and depth interviews. The most frequently used stimuli in these empirical researches are photographs or in situ observations (e.g. Hägerhäll, 2000; Palmer, 2004; Ode et al., 2008; Sevenant, 2010; Tveit, 2009). An objective manner to measure people's observation of landscapes, however, is provided by eye movement tracking. This technique allows the recording of the velocity and direction of eye movements (saccades) and the position and duration of fixations while observing images. Eye-tracking measurements are well known in the field of (environmental) psychology (e.g. Berto et al., 2008; Guerard et al., 2009; Patalano et al., 2010; Muller et al., 2012). It has, however, also been introduced in geography (e.g. Antonson et al., 2009), cartography (e.g. Ooms et al., 2012) and landscape science (e.g. De Lucio et al., 1996; Tveit et al., 2010). Because landscape photographs are often used in landscape perception research (Sevenant and Antrop, 2011), eye-tracking is a powerful tool for analysing people's observation of landscapes when represented on photographs. In this study, a homogeneous group of graduate geographers were asked to freely observe landscape photographs. During the experiment the participant's point-of-regard was constantly recorded by an eye tracker, so that his/her eye movements and fixations can be reconstructed and analysed. Examples of the recorded data are the number of fixations, the fixation duration, etc.

The aim of the experiment is to assess the impact of photographic properties and of landscape characteristics on the observation behaviour measured by Eye-tracking Metrics (ETM). In the photograph based approach, we determine if the type of photograph, used to represent a landscape, has an effect on the observation pattern. In particular, the influence of the horizontal and vertical view angles and the difference between normal and panoramic photographs are investigated. The main objective is to examine if people observe the same landscape differently if presented on different photograph types, varying in view angle.

The landscape based approach addresses the influence of two landscape characteristics on the observation pattern: the degree of openness and the degree of heterogeneity of a landscape. According to Weinstoerffer and Girardin (2000), openness is related to the ease with which an observer can obtain an extensive view over a landscape. Antrop (2007) defines open landscapes as landscapes which offer wide views in all directions, while enclosed landscapes are characterized by limited and obstructed views. In landscape studies, openness is often used as a criterion for landscape classifications (e.g. Meeus, 1995), landscape change (Van Eetvelde and Antrop, 2009) and visual landscape analysis and landscape preference analysis (Dramstad et al., 2006; Tveit et al., 2006; Ode et al., 2008). In this context, the degree of openness of a landscape is expressed as the proportion of open land (e.g. Weinstoerffer and Girardin, 2000; Palmer, 2004), the viewshed size (e.g. Germino et al., 2001; Gulinck et al., 2001; de la Fuente de Val et al., 2006) or the depth of view (e.g. Germino et al., 2001, Gulinck et al., 2001).

The heterogeneity or complexity of a landscape refers to the richness and diversity of elements in the landscape and their spatial organisation (Ode et al., 2010). At a given scale of observation, a landscape may be considered homogeneous when it is composed of few and mostly similar elements, while a heterogeneous landscape is composed of complex configuration of very diverse elements. The heterogeneity of landscapes is frequently described by landscape composition metrics for example richness, evenness, Shannon diversity (Wu et al., 2002; Uuemaa et al., 2009).

The approach of our study is twofold: it aims to detect differences in the observation pattern of open, semi-open and enclosed landscapes and of homogeneous and heterogeneous landscapes. In both approaches, the Eye-tracking Metrics are statistically analysed. In particular, we perform a comparison of means between the several groups (e.g. homogeneous and heterogeneous landscapes) to detect significant differences.

2.2 METHODS

2.2.1 Materials and stimuli

The stimuli for the eye-tracking experiment are photographs, representing different rural landscapes in Flanders (Belgium) (Figure 2.1). A distinction was made between open, semi-open and enclosed landscapes and between homogeneous and heterogeneous landscapes. Of each landscape five photographs with several focal lengths were taken: a panoramic photograph, a standard photograph, two detailed photographs (zoom 1 and zoom 2) and a wide angle photograph (Figure 2.2). Consequently, each photograph type differs in horizontal and vertical view angle, like summarized in Table 2.1. The standard photograph corresponds to the middle part of the panoramic photograph.

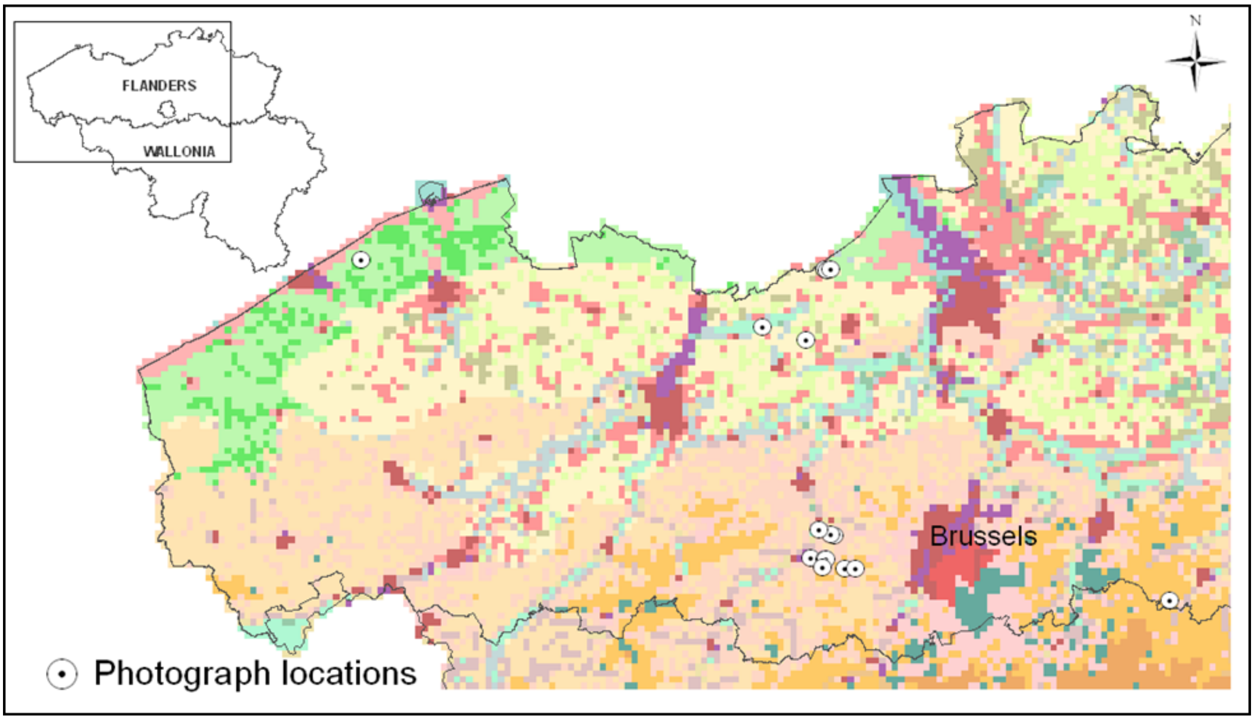

Figure 2.1 Photograph locations on the landscape characterisation map of Belgium (colours/grey tones represent landscape types) (Van Eetvelde and Antrop, 2009).

All photographs were taken during 10 days with similar weather conditions and in the same season (spring 2011), to avoid effects of vegetation transparency that would occur if the photographs were taken in different seasons. Furthermore, the photographs were made using a tripod to assure a constant shot height (1.70 meters).

In total, photographs of 56 landscapes were collected, of which finally 18 were selected for the experiment. As a result, the test consisted of 90 photograph stimuli in total (five per landscape). Figure 2.2 presents a photograph series of one of the tested landscapes. For the experiment, all photographs were framed in the same 1280x1025 pixel dark grey background (Figure 2.3) to guarantee an identical display size (constant height) and consequently allow a comparison between the different photograph types in the subsequent analysis of the recorded eye-tracking data. However, the statistical comparison between the panoramic photograph and the smaller photograph sizes may be complicated as the panoramic image covers a larger surface. To avoid this problem, an interest area, corresponding with what is represented in the standard photograph, was drawn over the panoramic photograph (Figure 2.3). This rectangle is invisible for the observer but allows the eye tracker to separately collect information about the observer's behaviour within this interest area.

Table 2.1 Photograph parameters.

Photograph type	Focal length	Horizontal view angle	Vertical view angle
Panoramic	50mm	70°	20.9°
Standard	50mm	31°	20.9°
Zoom 1	70mm	22.4°	15°
Zoom 2	100mm	15.8°	10.5°
Wide angle	18mm	75.1°	54.3°

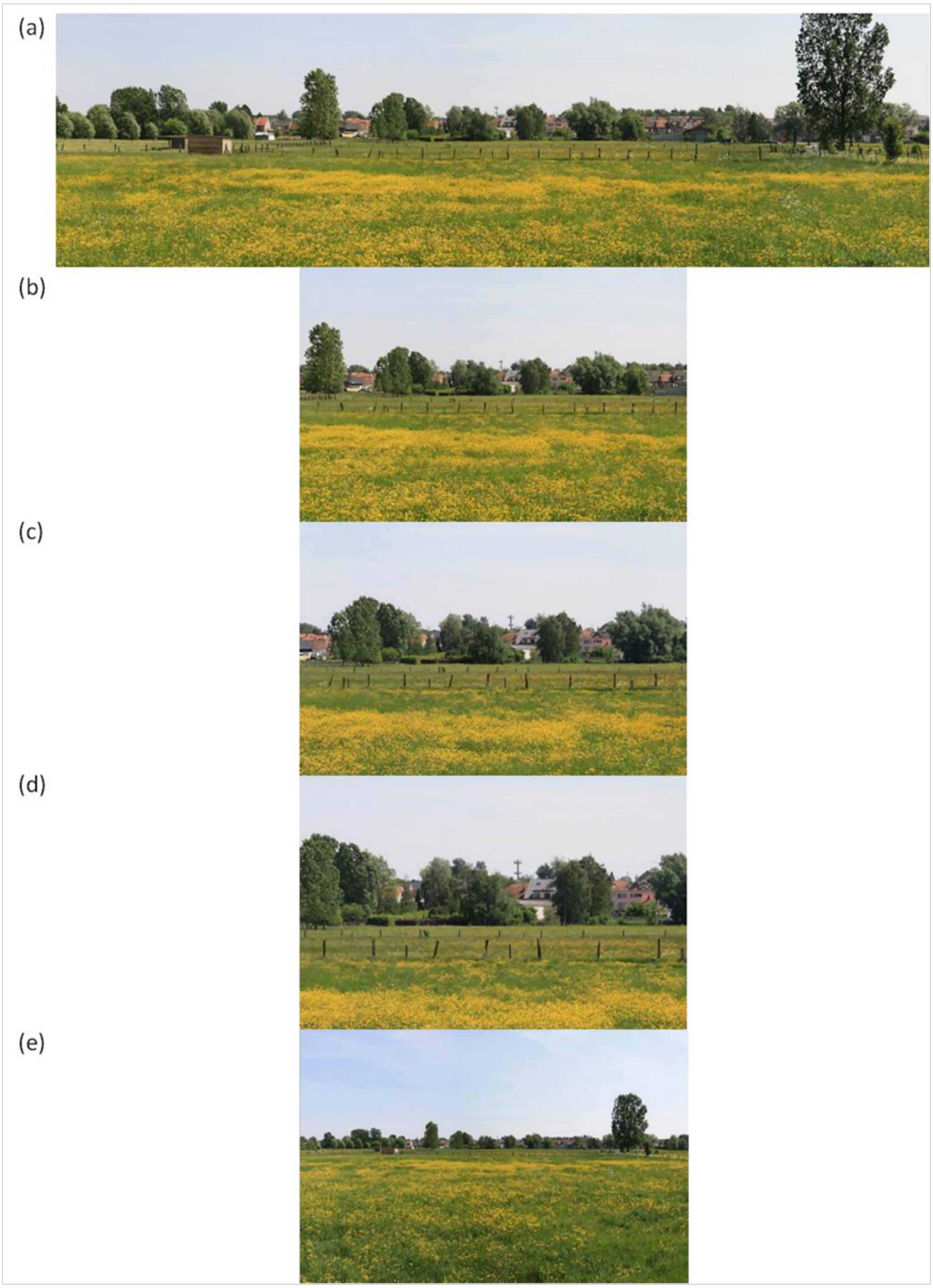

Figure 2.2 Example of five photograph types: (a) panoramic photograph, (b) standard photograph, (c) zoom 1, (d) zoom 2 and (e) wide-angle photograph.

Figure 2.3 Photograph stimuli, framed in a dark grey background to assure an identical display height and allow comparison between classic photographs and panoramic photograph types. The yellow rectangle represents the interest area corresponding to the standard photograph below.

2.2.2 Participants

In order to limit the bias towards the cultural, social and educational background of the observers, a homogeneous group of participants was selected. As a result, 23 graduate geographers (male and female, aged between 23 and 52) of the University of Ghent and Leuven participated as unpaid volunteers. As eye trackers are sensitive instruments, the participants were asked to wear contact lenses instead of glasses and renounce mascara in order to increase the accuracy of the eye-tracking measurements. Due to mascara the eye-tracking software could erroneously lock onto this dark area around the eye instead of onto the pupil (Holmqvist et al., 2011).

2.2.3 Eye-tracking equipment

The experiment was performed using an Eye Link 1000, developed by SR Research (Ontario, Canada) and able to record the point-of-regard of the observer every millisecond. This allows a continuous registration of the participant’s eye movements. In particular, low power infrared light is sent into the eye, where it is reflected by the cornea and the retina (Jacob and Karn, 2003; Poole and Ball, 2005). This reflection illuminates the pupil and cornea, which enables the signal processing unit to identify the centre of the pupil and the location of the corneal reflection. Subsequently, the vector between them is measured and the position of the point-of-regard is calculated (Poole and Ball, 2005) and expressed in a horizontal and vertical coordinate (Jacob and Karn, 2003). Due to the high sample rate (1000Hz) and the duration of each session (15 seconds x 90 photographs), this procedure generates a large amount of raw data. However, these data allow a complete reconstruction of the observer’s entire scan path, which is defined as a complete sequence of fixations and interconnecting saccades (Poole and Ball, 2005). In addition, it is possible to identify the areas in the image that drew most attention, generally called centres of attention (Buswell, 1935). Although both eyes are used for viewing, the instrument only records movements of one eye (left or right depending on the subject’s eye specifications). Furthermore, the observer's head was fixed on a chin rest to restrict head movements and increase the accuracy of the measurements (Holmqvist et al., 2011).

2.2.4 The eye-tracking experiment

The experiment was executed during four days in July 2011 in an isolated room in a laboratory at Ghent University, so that participants could not be distracted. In addition, the room was darkened as the infrared light in direct sunlight would disturb the infrared illumination of the eye tracker (Holmqvist et al., 2011). Each test was preceded by a calibration procedure to match the pupil characteristics with the corresponding coordinates of the point-of-regard. This was achieved by a predefined calibration trial during which the subject was asked to fix nine dots appearing separately in an invisible, regular 3x3 grid (Holmqvist et al., 2011). Only if a dot was precisely fixed for longer than a certain threshold time, the system recorded that pupil-centre/corneal-reflection relationship as corresponding to that specific x,y coordinate on the screen and moved on to the next dot. This was repeated for the nine dots of the regular grid to assure an accurate calibration over the whole screen (Goldberg and Wichansky, 2003). In addition, this procedure was repeated each time the deviation error increased due to unintentional small head movements or after a short break.

During the experiment, the subjects were seated 50 cm from the 1280x1025 pixel display screen and asked to freely view the photographs. In total, the test consisted of observing 90 randomly displayed photographs, each for 15 seconds. This specific display time is based on similar studies done by De Lucio et al. (1996) and Berto et al. (2008). The participants were given no specific tasks; no particular information needed to be extracted or remembered. Free-viewing was chosen because in the real life people do not observe landscapes with a task in mind. For example, during a walk people will mostly look at the landscape freely and unrestrictedly. In the free-viewing experiment this condition was reproduced. Prior to each trial the subjects were instructed to fix a dot shown in the centre of a blank screen to check for increasing measurement errors and to provide consistency on the initial conditions of the observation path of each photograph. During the trials the system constantly recorded the point-of-regard of the subject. To assure full concentration of the participants and avoid errors caused by head movements, subjects were prohibited from speaking during the test. At each moment during the experiment, however, participants could interrupt the session in case of discomfort or tiredness. The next trial was then started after a recalibration.

2.2.5 Photograph sorting

After the eye-tracking experiment, the subjects were asked to classify the 18 landscapes in order to create categories based on the degree of openness and heterogeneity. First, the participants were instructed to select the six landscapes with the widest views, followed by the six landscapes characterized by the absence of wide views. These categories respectively correspond to the 'open landscapes' and 'enclosed landscapes'. The remaining six landscapes belong to the 'semi-open landscapes'. Participants were not directly asked to select the most open and enclosed landscapes as their individual definition of open and enclosed landscapes may vary. A more objective criterion - the presence of wide views, based on Antrop's (2007) definition of open and enclosed landscapes - was used to avoid this problem. Finally, three groups (open/semi-open/enclosed) of six landscapes each were obtained by attributing each landscape to the group in which the majority of the participants classified it.

Second, the exercise was repeated to divide the landscapes photographs into homogeneous and heterogeneous landscapes. The participants were asked to divide the 18 landscape pictures into two equal groups, based on the amount of variety in the photograph. Again, no direct question was asked about 'homogeneous or heterogeneous landscapes' to avoid classifications based upon personal definitions of these concepts. The final two groups each consist of nine landscapes, either mostly classified as 'unvaried' (homogeneous landscapes) or as 'varied' (heterogeneous landscapes).

In both cases, the obtained groups were subsequently used to examine the difference in gaze pattern between open, semi-open and enclosed landscapes and between homogeneous and heterogeneous landscapes (landscape based approach, see section 2.3.2). The sorting exercise was performed using the panoramic landscape photographs as these give the most complete idea of a landscape.

2.2.6 Data processing and statistical analysis

Before starting the data analysis, the raw data needed to be converted into understandable and usable metrics. Most importantly, a distinction between fixations and saccades was required. Poole and Ball (2005) define a fixation as "the moment when the eyes are relatively stationary, taking in or encoding information". Jacob and Karn (2003) are more specific in their definition: "a fixation is a relatively stable eye-in-head position within some threshold of dispersion (typically 2°) over some minimum duration (typically 100-200 milliseconds) and with a velocity below some threshold (typically 15-100 degrees per second)". As there is no standard technique for identifying fixations (Jacob and Karn, 2003) and it is advised to set the lower threshold of a fixation on at least 100 milliseconds (Inhoff and Radach, 1998), we decided to define each stationary eye position, lasting for at least 100 milliseconds, as a fixation. Saccades are then defined as the eye movements occurring between fixations with the purpose to move the eyes to the next viewing position (Poole and Ball, 2005). The conversion from raw data into fixations and saccades was realized using the 'Data Viewer', a software program supplied with the equipment. Once the fixations are defined, this software produces Excel-files containing complete, well organized and usable trial and fixation reports, in which numerous metrics like the number of fixations, the fixation duration and position, the number of saccades, the saccade velocity and amplitude etc. are listed. As a result, these files were suitable for performing the statistical analysis, executed in the software package SPSS.

Not all metrics, recorded by the eye-tracking system are analysed in this study. Instead, we selected a number of basic Eye-tracking Metrics that provide information about the main observation pattern. These are fixations and saccades and their properties (Poole and Ball, 2005). Throughout the entire study the metrics of interest are therefore the following: the number of fixations, the fixation duration, the number of saccades, the saccade amplitude and velocity, the observed horizontal area and the observed vertical area. The latter are both derived from the fixation coordinates, using the principle of the minimum bounding rectangle. For example, the difference between the x-coordinate of the most extreme fixation in the right-hand side of the image and the x-coordinate of the most extreme left-hand side fixation provides the proportion of the photograph observed in the horizontal direction. Analogously, the difference between the y-coordinate of the most extreme fixation in the upper part of the image and the y-coordinate of the most extreme fixation in the lower part generates the proportion of the photograph observed in the vertical direction.

The first goal of the experiment is to test whether the photograph type has an effect on the observation pattern of landscape photographs (photograph based approach). Therefore, a comparison of means between the different photograph types was carried out for the metrics measured by the eye-tracking system. It has been demonstrated that many eye-tracking measures do not follow a normal distribution (Holmqvist et al., 2011). To test this, we first performed a Kolmogorov-Smirnov test. The results indicate that none of the ETM is normally distributed. Consequently, a Mann-Whitney test (2 samples) and Kruskal-Wallis test (k samples) for non-parametric data were used for testing the equality of means, based on ranks[1]. Where the Kruskal-Wallis test indicated unequal means, further information about the comparative magnitudes of the means was obtained using a Dunn's test. Based on these tests, groups of similar means were formed and differing means were identified.

The influence of the landscape characteristics (degree of openness and heterogeneity) on the observation pattern was tested similarly. To avoid effects of the photograph

[1] In the General Discussion (section 7.4.3), the analyses are redone using the more performant Friedman and Wilcoxon Signed Rank tests which also take into account possible dependencies of the observations, given that all participants were presented with the same set of photographs.

type, the statistical analysis was only executed on the panoramic photograph type, because panoramic images offer the most complete view on the landscape.

2.2.7 Data visualization

The Data Viewer provides a tool to display all recorded data on the original photographs. This can either be created for one individual subject or for the entire group of participants. Although this does not enable a strong analysis of the data, it is a helpful tool to visualize the results of the statistical analysis. Different kinds of maps can be created. Figure 2.4 is an example of the visualization of the fixations and saccades made by one subject. The circles represent the fixations, while the arrows illustrate the eye movements between two fixations (saccades). In both cases the numbers indicate the duration of the fixation/saccade in milliseconds. Figure 2.5 is an example of a 'heat map', derived from the fixation (and saccade) map and introduced by Wooding (2002). This map shows the centres of attention, in this case of the entire group of participants. The red zones indicate the areas that have been observed most frequently and intensively.

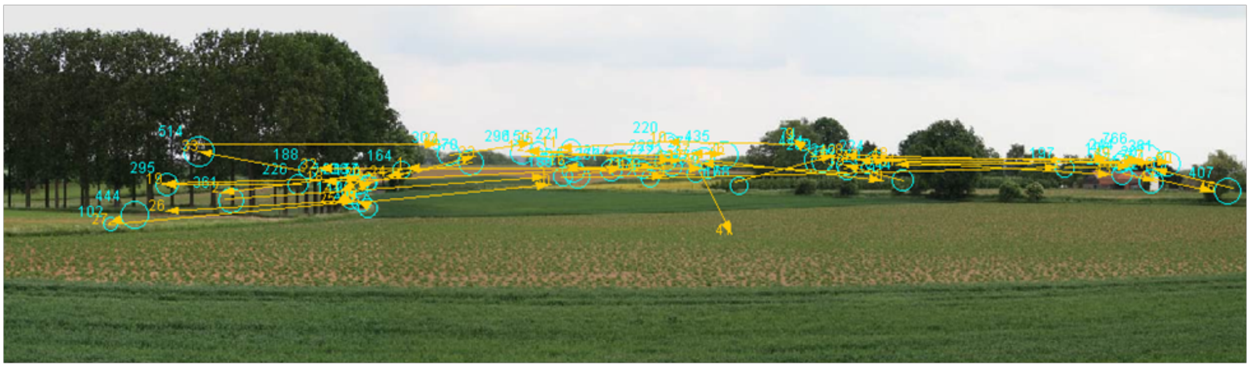

Figure 2.4 Visual output of one test person: fixations (circles) and saccades (arrows) indicating the eye movements.

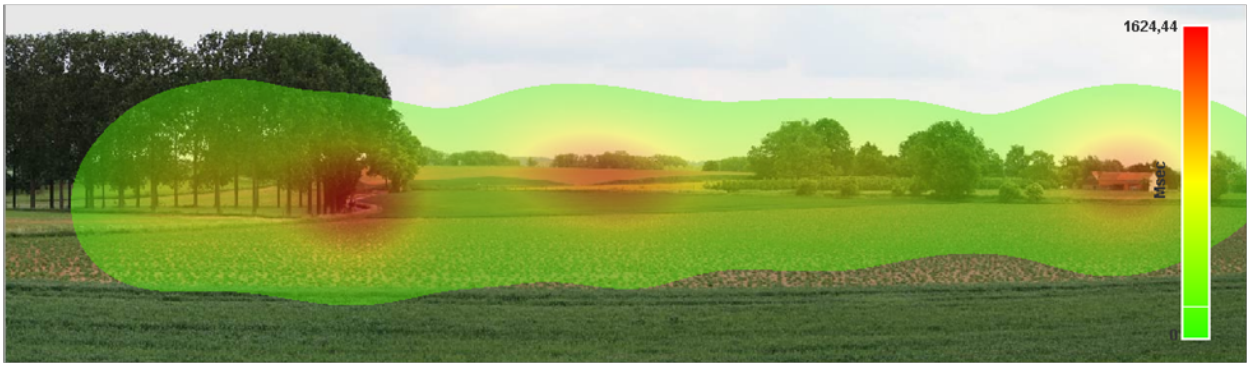

Figure 2.5 Heat map of entire test population, showing the centres of attention. Red zones correspond to the most frequently and intensively observed areas (mean fixation duration of 1624.44 milliseconds). Non-coloured areas have not been perceived by the participants.

2.3 RESULTS AND DISCUSSION

2.3.1 Photograph based approach

First, the Kruskal-Wallis and Dunn's test indicate a significant difference in the number and duration of fixations and in the number, amplitude and velocity of saccades for the panoramic photograph compared to the other photograph types ($P < 0{,}05$) (Table 2.2). For these ETM, with exception of the saccade velocity (see further), no significant differences were found between the standard photograph, zoom 1, zoom 2 and the wide angle photograph.

Table 2.2 Results of the Kruskal-Wallis and Dunn's test per photograph type[2]. The ranks are the results of the Kruskal Wallis test, grey tones indicate the outcome of the pairwise Dunn's tests. Per ETM, grey tones indicate groups of similar means, with, if significantly different, maximum values in darkest grey and minimum values in lightest grey. N gives the number of observations.

Eye Tracking Metric	N	Mean rank per photograph type					P
		Panoramic	Standard	Zoom 1	Zoom 2	Wide angle	
Number of fixations	83,001	48,662	39,516	39,599	39,864	39,231	0.000
Fixation duration	83,001	38,469	42,468	42,077	42,284	42,474	0.000
Number of saccades	81,300	47,773	38,644	38,764	39,059	38,371	0.000
Saccade amplitude	81,300	49,054	37,964	37,732	38,422	39,153	0.000
Saccade velocity	81,300	48,116	38,327	37,835	38,928	39,202	0.000
Observed horizontal area	2,070	1,848	858	838	768	866	0.000
Observed vertical area	2,070	889	1,014	1,055	1,144	1,075	0.000

In particular, the experiment reveals that people generate more fixations in panoramic photographs. According to Duchowski (2007), a larger amount of fixations in the same observation time will increase the observer's capacity to recognize and memorize what is represented on the image. A number of factors may explain the higher number of fixations in panoramic photographs. In the first place, the higher number of fixations could result from the larger size and surface of panoramic photographs. As people tend to scan the whole image, more fixations will be generated in larger images. On the other hand, a panoramic photograph offers a broader view on a site or landscape, with a larger number of objects to observe. In order to know whether panoramic photographs are observed more extensively, like suggested by the higher number of fixations, a proper comparison with respect to the photograph surface needs to be established. This is achieved by comparing the middle part of the panoramic photograph (interest area in Figure 2.3) with the standard photograph. Both are identical in size and representation, except that the interest area is part of a larger photograph. The results of this comparison indicate that significantly more fixations occur in the interest area than in the standard photograph ($P < 0,05$) (Table 2.3). Thus, on the same photograph, a larger number of fixations are made when the photograph

[2] These results are confirmed by the Friedman and Wilcoxon Signed Rank test (see General Discussion). In order to be complete, the real mean values are provided in the Appendix.

is part of a panoramic image. A landscape image might consequently be observed more extensively if a panoramic photograph is used. In addition, panoramic landscape photographs may be easier to recognize and to remember.

Table 2.3 Comparison between the interest area on the panoramic photograph and the standard photograph, based on a Mann-Whitney test. Per ETM grey tones indicate groups of similar means, with, if significantly different, maximum values in darkest grey and minimum values in lightest grey[3]. N gives the number of observations. Absolute values of the mean ranks are smaller than in Table 2.2 because this test is performed on the mean values of the ETM of the interest area.

Eye Tracking Metric	N	Mean rank		P
		Interest area on panoramic photograph	Standard photograph	
Number of fixations	828	584	245	0.000
Fixation duration	828	208	621	0.000

It is, however, not the number of fixations but the fixation duration that determines how easily photographs and images in general are processed and encoded. It is known that the fixation duration is an indication of a participant's difficulty extracting information from or interpreting an image (Fitts et al., 1950; Goldberg and Kotval, 1998; Duchowski, 2007) as it reflects the processing-time applied to the object being fixated (Just and Carpenter, 1976). In particular, it has been demonstrated that longer fixation durations indicate difficulty in extracting information (Just and Carpenter, 1976). Consequently, visual representations associated with long fixations are less meaningful to the observer than images associated with short fixations (Just and Carpenter, 1976; Goldberg and Kotval, 1999). Our results indicate shorter fixations in the entire panoramic photographs (Table 2.2) and in the interest area (Table 2.3), which suggests that information is extracted easier from panoramic landscape

[3] These results are confirmed by the Friedman and Wilcoxon Signed Rank test (see General Discussion). In order to be complete, the real mean values are provided in the Appendix.

photographs. This is explained by the broader context provided by panoramic photographs, which offers a more complete and holistic view on a landscape. As a consequence, the effort and time to identify and interpret potentially ambiguous landscape objects is expected to be less.

As fixations and saccades are complementary, a higher number of fixations results in a higher number of saccades in panoramic photographs. However, no encoding takes place during saccades, which means that this metric cannot be used to gain insight into the complexity of a landscape or landscape object (Rayner and Pollatsek, 1989). Instead, the number of saccades is related to the search pattern. According to Goldberg and Kotval (1999) more saccades indicate more searching. This means that people are searching or exploring more in panoramic photographs compared to the other photograph types. This tendency is explained by the broader horizontal view angle of panoramic photographs, which exposes a larger part of the landscape to the observer. As a result, the photograph represents a larger area with more landscape objects to be explored.

Furthermore, the saccades' amplitude and velocity seems to be higher in panoramic photographs. As saccades re-orient the eyes to the next viewing position and thus to the next fixation, the saccades' amplitude provides information about the distance from which the attention is drawn to an object. The larger this distance, and thus the larger the amplitude of the saccades, the more meaningful the cues in the image will be (Goldberg et al., 2002). In panoramic photographs, objects seem to catch the observer's attention from a larger distance. In addition, re-orientations of the eyes are executed more rapidly, which suggests a higher readability of this type of photograph. It is possible that these larger (and faster) saccades are due to the larger image that is represented by the panoramic photograph. However, the saccades made in the interest area on the panoramic photograph - thus which start and end in the interest area - seem to be larger as well, compared to the standard photograph (Table 2.3). This means that the larger amplitude of the saccades occurring in panoramic photographs is independent from the image size. In the detailed photographs (zoom 1) significantly slower saccades were reported.

Another significant difference between panoramic photographs and the other photograph types is found in the observed horizontal and vertical area of the image ($P < 0{,}05$) (Table 2.2). Again, no significant differences were found between the other photograph types, except for the second zoom photograph. In panoramic photographs, the vertical proportion of the image that is observed is smaller. This is inherent to the characteristics of this kind of photograph, which subjects tend to scan in a mainly horizontal direction, apparently focussing less on the vertical dimension. The opposite applies to the detailed photographs (zoom 2), of which a larger vertical proportion is observed, compared to the other photograph types. This kind of photograph offers more details to the observer, and as a result, objects are represented in a larger size, covering a larger proportion of the photograph. As the participants observed these objects, automatically a larger vertical proportion of the image is explored.

2.3.2 Landscape based approach

The statistical analysis points out that the degree of openness of a landscape has a significant effect on the number of fixations and saccades, the fixation duration, the saccade velocity and the observed vertical area of the photographs ($P < 0{,}05$) (Table 2.4). In particular, open landscapes are associated with a smaller amount of fixations and saccades, while the fixation duration and saccade velocity are larger. Less fixations and saccades indicate less searching and thus less visual exploration of the landscape (Goldberg and Kotval, 1999). This is a consequence of the nature of open landscapes: objects, that may obstruct the view, are missing or only occur as small elements in the background of the landscape, creating its open character. Consequently, photographs of open landscapes do not exceed in variety and edges, but are rather monotonous, which apparently does not stimulate people to visually explore these types of landscapes. This is in line with Mackworth and Morandi (1967), who found out that subjects make more fixations in images or areas containing contours than in images composed of unbounded textures. Longer fixations suggest that information extraction and interpretation of the image is difficult (Just and Carpenter, 1976). Again, the unvaried character of open landscapes supports this finding. In addition, the potentially eye-catching larger objects only occur as small background elements in the photograph, which makes it difficult to obtain information about them and which may explain the longer fixations. In enclosed landscapes the opposite occurs: fixations are shorter. This suggests that enclosed landscapes may be easier to recognize as large objects are mainly situated in the foreground or middle plan of the photograph. In addition, larger objects can be experienced as 'threatening' or 'dangerous' (Appleton, 1975). When confronted to numerous large objects in their field of view, people might make short fixations on each of these objects to quickly determine which of them are really important or indeed threatening. This also supports the shorter fixation durations in enclosed landscapes. Furthermore, these view-obstructing objects, like trees, forests or buildings seem to be observed from top to bottom, which explains why enclosed landscapes are dominantly observed in a vertical direction.

Table 2.4 Results of the Kruskal-Wallis and Dunn's test per landscape characteristic, tested on the panoramic photographs[4]. The ranks are the results of the Kruskal Wallis test, grey tones indicate the outcome of the pairwise Dunn's tests. Per ETM, grey tones indicate groups of similar means, with, if significantly different, maximum values in darkest grey and minimum values in lightest grey. N gives the number of observations.

Eye Tracking Metric	N	Mean rank Openness			P	Mean rank Heterogeneity		P
		Open	Semi-open	Enclosed		Homogeneous	Heterogeneous	
Number of fixations	83,001	40,632	42,038	41,820	0.000	41,008	41,985	0.000
Fixation duration	83,001	42,147	41,435	40,931	0.000	41,622	41,382	0.150
Number of saccades	81,300	39,623	41,217	41,094	0.000	40,155	41,136	0.000
Saccade amplitude	81,300	40,916	40,116	40,826	0.000	41,865	39,396	0.000
Saccade velocity	81,300	41,014	40,225	40,621	0.000	41,408	39,843	0.000
Observed horizontal area	2,070	1,070	1,043	994	0.059	1,031	1,040	0.747
Observed vertical area	2,070	985	998	1,123	0.000	1,142	929	0.000

The degree of heterogeneity of a landscape also influences the observation pattern (P < 0,05). Table 2.4 shows that homogeneous and heterogeneous landscapes differ in the number of fixations and saccades, the saccade amplitude, the saccade velocity and the observed vertical area. Homogeneous landscapes are associated with less fixations and saccades compared to more heterogeneous landscapes. In addition, the participants made longer and faster eye movements in homogeneous landscapes. These findings indicate a weaker visual exploration of this type of landscape, which can be explained by its more monotonous character and the scarcity of interesting objects within the field of view presented by the photograph. However, the saccades are longer and faster, which suggests that people quickly glance through the entire scene

[4] These results are confirmed by the Friedman and Wilcoxon Signed Rank test (see General Discussion). In order to be complete, the real mean values are provided in the Appendix.

without finding interesting elements to fix upon. This also enlarges the vertical area of the image that is observed.[5]

Finally, nor the openness, nor the degree of heterogeneity of a landscape seems to have an influence on the observed horizontal area of a photograph ($P > 0,05$).

2.4 CONCLUSIONS

The aim of this study was to test the effects of the photograph properties and landscape characteristics on the observation pattern, measured by Eye-tracking Metrics. The photograph based analysis points out that the photograph properties, and in particular the view angles, do influence the visual observation of landscape photographs. Panoramic photographs seem to be observed in a significantly different way than standard, detailed and wide angle photographs. In panoramic photographs, more but shorter fixations are generated, suggesting that this type of photograph is observed more extensively and that information extraction may be facilitated. Consequently, a landscape image may be easier to recognize and memorize when presented as a panoramic photograph. This conclusion is particularly important for studies using landscape photographs in combination with questionnaires. Responses will probably be more adequate and detailed if panoramic photographs are used.

In the landscape based approach, we tested if the degree of openness and heterogeneity of a landscape affects the observation pattern. The analysis clearly reveals that both landscape characteristics do have an influence. The long fixation durations suggest that the visual exploration of open landscapes is less extensive and that information extraction is hampered. The opposite conclusion applies to enclosed landscapes, which seem to be easier to interpret. Furthermore, homogeneous landscapes are expected to be explored less intensively compared to more heterogeneous landscapes due to their rather unvaried character. Instead, the entire

[5] A more nuanced interpretation of these results based on more elaborated analyses is provided in the General Discussion, section 7.2.

landscape photograph is quickly scanned because of the absence of attractive or interesting objects. Heterogeneous landscapes are more diverse and thus more 'entertaining', which explains the stronger visual exploration of this kind of landscape.

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CHAPTER 3: INVESTIGATING THE VISUAL EXPLORATION OF THE RURAL-URBAN GRADIENT USING EYE-TRACKING

Modified from:

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ABSTRACT We analyse if the visual exploration of landscape photographs is influenced by the urbanization level of the landscape and whether this is correlated with visual landscape complexity. We determine if differences in viewing behaviour are related to differences in complexity, expressed by the photograph's spectral entropy. An eye-tracking experiment is conducted to measure visual behaviour, while observing the photographs. A more extensive and dispersed exploration is found in more urbanised landscapes. The fixation pattern is more restricted and clustered in weakly urbanised landscapes. When buildings are lacking, this trend cannot be extrapolated since these landscapes seem to elicit an unexpectedly extensive exploration. The urbanisation level is positively correlated with the visual complexity, indicating its potential influence on the viewing behaviour.

KEYWORDS: Perception of outdoor space, landscape photographs, visual landscape complexity, spectral entropy, urbanisation.

3.1 INTRODUCTION

In environmental perception research, the relationship between the complexity of a scene and its visual exploration has been briefly investigated in the 1960's (e.g. Berlyne, 1963 and Wohlwill, 1968, who demonstrated that the amount of exploratory behaviour linearly increases as a function of complexity). However, nowadays much more accurate techniques are available to study this topic in greater detail. For example, Wohlwill (1968) asked a number of respondents to view a diversity of natural and man-made environmental scenes, varying in complexity, and used the number of times an image was seen – each image was flashed for a brief moment and participants could choose how often they wanted to see it – as an indicator of the exploration of the scene. However, the actual visual exploration – how the scene content was inspected and which kind of scan paths were produced – was not measured. In addition, the complexity of the images was estimated by human ratings, which may be less consistent than more objective measures of complexity (Yu and Winkler, 2013) (see section 3.2). Finally, Wohlwill included natural as well as man-made landscapes differing in complexity, but the relationship between the degree of urbanisation and complexity was not investigated.

In our study, we address these points by conducting an eye-tracking experiment in which the participants are asked to observe landscape photographs ranging from rural scenes to completely built environments. The aim of the experiment is to find out if the visual exploration of landscape photographs differs depending on the landscape type in terms of urbanisation and if potential differences in this viewing behaviour could be related to the visual complexity of the landscapes, as suggested by Wohlwill (1968) and Kaplan and Kaplan (1989) in their Information Processing Theory. Therefore, the photographs were classified into 5 classes according to the degree of urbanisation (rural to urban) by the participants. To validate these classes the percentage of urbanised area in each photograph was measured in order to allow a correlation analysis between the perceived and measured degree of urbanisation. Furthermore, the complexity of the photographs was quantified by calculating the spectral entropy of each image. As this measure is based on the image's pixel colour values, it can be used as an objective and consistent indicator of image complexity. A correlation analysis was subsequently performed between the degree of urbanisation (urbanisation classes and percentage of urbanised area) and the visual landscape complexity given by the spectral entropy. This analysis was carried out to verify if differences in the visual exploration of diverse landscape types are related to their visual complexity. The eye-tracking experiment allows us to measure the observers' visual exploration of the landscape photographs by recording eye movements and fixations while observing images. This enables the reconstruction of the entire scan path when looking at a photograph and the identification of the fixated elements. As a result, accurate data concerning the actual visual behaviour can be obtained and analysed in detail (Duchowski, 2007). The main aim of this study can be summarized by two questions. (1) Is the visual exploration of landscape photographs dependent on the landscape type in terms of urbanisation and (2) is there a relationship between the degree of urbanisation and the visual complexity of the landscape? In other words, could the visual complexity of the landscape give rise to different viewing patterns?

3.2 BACKGROUND: VISUAL LANDSCAPE COMPLEXITY

The visual landscape is characterized by a multitude of visual concepts as described by Ode, Tveit, and Fry (2008). Complexity is one of these. Kaplan and Kaplan (1989) define complexity as 'the number of different visual elements in a scene' or as 'a scene's richness'. Besides the diversity of elements, the amount of edges between these elements is also believed to contribute to the degree of complexity (Germino et al., 2001). In more trivial terms, Stamps (2004) describes complexity as 'how much is going on in a scene, how much there is to look at'. However, it is not easy to quantify this in an objective measure. So far, several metrics for mathematically calculating landscape complexity have been developed in the field of landscape ecology (Li and Wu, 2007; Ode and Miller, 2011). Such metrics, which are commonly calculated in Fragstats (McGarigal et al., 2012), include number of land cover classes, number of patches, patch richness, Shannon Diversity Index, aggregation index, edge density, fractal dimension etc. (e.g. Honnay et al., 2003; Palmer, 2004; de la Fuente de Val et al., 2006; Ode et al., 2010; Persson et al., 2010; Ode and Miller, 2011). However, these variables are mostly calculated based on maps (e.g. Phillips et al., 1999; Papadimitriou, 2002; Palmer, 2004; Roschewitz et al., 2005; Concepción et al., 2008), satellite imagery (e.g. Honnay et al., 2003) or aerial photographs (e.g. Persson et al., 2010). Less numerous are studies in which the complexity of a landscape is determined based on field photographs or visualisations of the environment (e.g. Sang et al., 2008; Ode and Miller, 2011), although this can be useful since the complexity of a map is not necessarily the same as the complexity in an image (Sang et al., 2008). Moreover, studies in which complexity is computed based on landscape images are mostly working with computer-aided edited photographs or completely simulated views of the landscape (e.g. Hunziker and Kienast, 1999; Ode and Miller, 2011). Although the validity of using simulations in landscape research has been demonstrated (Bishop and Leahy, 1989), such images remain less realistic and less detailed than original landscape photographs (Ode and Miller, 2011). These are important issues when assessing visual complexity directly on an image. A similar issue occurs when assessing complexity based on images in which patches of different land cover types have been delineated (e.g. Ode and Miller, 2011). Although such 'simplified' images are appropriate for calculating a number of metrics concerning complexity, they are not suitable for calculating image complexity as there is too much information loss due to the classification. In addition, classifications always contain a certain degree of subjectivity. In the Methods section we explain how these earlier studies have influenced the choices we made in setting up our experiment.

3.3 METHODS

3.3.1 Visual stimuli

Our study focuses on how people perceive different types of landscapes. Therefore, we use terrestrial landscape photographs. Maps are considered unsuitable for this purpose as they do not provide images of the actual landscape, but only give a graphic

2D spatial configuration of the environment, showing the features present in a specific area and indicating how these are spatially arranged. In addition, we opted for using original non-edited landscape photographs for two reasons. First, we want to get as close as possible to a real life perception of landscapes. Thus, edited and simulated photographs are not appropriate. Second, because the photographs are used in an eye-tracking experiment, it is important that the images are as neat as possible because artefacts of editing and simulation might catch the attention and thus bias the eye movement pattern.

The photographs were all taken in the same season (summer) to provide consistency in the condition of the vegetation. We used a constant focal length of 50mm and a tripod to assure equal view angles (31° x 21°) and a constant shot height (1.70m). The horizon was always positioned on two thirds up image, leaving one third of sky. All selected landscapes were situated in Belgium and northern France and ranged from completely rural landscapes to completely urban ones (Figure 3.1). In total, 74 landscape photographs were used in the eye-tracking experiment. This number is large enough to assure sufficiently large categories of urbanisation, necessary to allow statistical analyses. It is also facilitates keeping the duration of the experiment manageable as well as handling of the obtained data (Duchowski, 2007).

Figure 3.1 Example of the landscape photographs showing the rural-urban gradient used in this study.

3.3.2 Measuring visual landscape complexity

In this study we objectively measure the visual landscape complexity, directly on the original landscape photographs (not, for instance, on images classified into land cover types), which are also used in the eye-tracking test. It is assumed that landscape complexity is correlated with image complexity as calculated from the pixel value distribution, which we test in this study (see below). For this purpose, ‘entropy’ is an appropriate measure as it is a statistical and natural measure of complexity, which can be easily calculated directly on an image (Perkiö and Hyvärinen, 2009). In particular, it calculates the amount of visual diversity and variation in an image (Stamps, 2003), two factors which have been demonstrated to determine complexity (Fiske and Maddi, 1961; Day, 1967; Wohlwill, 1968). Furthermore, this measure of complexity is calculated independently of the participants’ evaluations of complexity. In his literature review, Stamps (2003) states that numerous studies have demonstrated image entropy to be highly correlated with rated visual diversity and with visual complexity ($r = 0.91$). Consequently, entropy appears to be a very strong indicator of subjective impressions of visual complexity in landscape scenes (Krampen, 1979; Stamps, 2003). This is important for our study as we are interested in the visual complexity of a landscape view, as perceived and experienced by people.

For each landscape photograph, we used Python to compute the spectral entropy, a complexity measure introduced by Zaccarelli, Li, Petrosillo, and Zurlini (2013) and recently used in landscape ecology studies (e.g. Zurlini, Petrosillo, Jones, and Zaccarelli, 2013). Spectral entropy is the entropy of the spectral distribution of the Fourier-transformed image, i.e. the entropy of the image’s frequency distribution (Ellerkmann et al., 2004; Vanluchene et al., 2004). Spectral entropy values range between 0 (low complexity) and 1 (high complexity) (Viertiö-Oja et al., 2004). A low-frequency image, for example an image that only consists of a few colours, will have low spectral entropy as there is not much variation in pixel values. A high-frequency image, for example a ‘busy’ image made up of many different colours, will be characterized by a high spectral entropy because of the large variation in pixel values. As such, spectral entropy can be used as a measure of the complexity of an image. As spectral entropy takes into account an image's spectral distribution following its Fourier transformation (Vanluchene, Struys, Heyse, and Mortier, 2004), we first calculated this transform for each photograph. Subsequently, from this image, the power spectral density was computed and normalized. In the last step, the entropy was calculated using the classic sum (see Ellerkmann, Liermann, Alves, Wenningmann, Kreuer, Wilhelm, Roepcke, Hoeft, and Bruhn (2004) and Viertiö-Oja, Maja, Särkelä, Talja, Tenkanen, et al. (2004) for detailed information about the calculation of spectral entropy, which is beyond the scope of this paper).

3.3.3 Classification of landscapes based on the degree of urbanisation

The landscape photographs were sorted by the participants into classes of urbanisation, ranging from rural to urban (Figure 3.1). The degree of urbanisation was used as a discriminating factor for several reasons. First, we want to further explore Wohlwill's study (1968), in which a range of natural and man-made scenes from the geographic environment is used. Consequently, we used a similar range of photographs. Second, one of the aims of our study is to investigate whether the visual landscape complexity is correlated with the degree of urbanisation of a landscape. We chose this parameter as it has been demonstrated that the diversity and complexity of a landscape have been demonstrated to increase with urbanisation, when calculated on satellite imagery (Honnay et al., 2003). In our study, we analyse if this is also true when computed on terrestrial landscape photographs. Finally, buildings have been found to catch the attention (Dupont et al., 2015), which suggests that the presence of man-made built area may affect the overall viewing pattern. In order to analyse how people visually react to different amounts of buildings, we opted for a range of landscapes varying in degree of urbanisation. For finding differences in visual behaviour between these different urbanisation levels, a classification of the photographs was indispensable (see below).

The categories were obtained using the Q-sort method like described by Pitt and Zube (1979). In particular, participants were asked to sort the 74 landscape photographs into

5 classes of urbanisation. As each person's interpretation of urbanisation may vary, we used a more objective criterion to perform the sorting: the presence of built area in the image. For the sorting task, the participants were presented with all photographs on a desk and were asked to first remove the 12 scenes which they thought were least characterized by built area. These landscapes were classified as 'Rural'. The second task consisted of picking out the 12 scenes in which they thought the most built area was present (= 'Urban'). For the remaining 50 photographs these two steps were repeated but at each time selecting 16 photographs instead of 12 (respectively 'Semi-rural' and 'Semi-urban'). The remaining 18 landscape scenes formed the last 'Mixed' class. Afterwards, scores were assigned to each class as follows: rural = score 0, semi-rural = score 1, mixed = score 2, semi-urban = score 3 and urban = score 4. For each photograph, these scores were summed across participants and an average urbanisation score was calculated. These means determined to which class of urbanisation each photograph was assigned. However, a number of photographs seemed to balance between two categories (scores close to e.g. 1.5, 2.5 etc.) and could therefore not be unequivocally assigned to one class. Therefore, we decided to leave these photographs out of the analysis. As a result, each of the 5 classes consisted of 10 photographs. The Q-sorting was performed after the eye-tracking test to avoid biasing the viewing pattern due to recognition when seeing the images for a second time.

3.3.4 Validation of urbanisation classes

The classification of the urbanisation classes was compared to the objectively calculated percentage of urbanised area in each photograph in order to find out if the perceived urbanisation corresponds to the measured urbanisation and thus to evaluate the validity of the categories. For this purpose, all buildings and concrete surfaces were manually delineated in each photograph. Subsequently, the total area of these polygons was calculated to obtain the percentage of urbanised area in each image. A correlation analysis and linear regression were performed between the urbanisation classes and the measured degree of urbanisation. The Spearman correlation coefficient was used because the variables did not follow a normal distribution (P-value of 0.000 in Shapiro-Wilk test of normality). Five urbanisation classes were used (scores 0-4), as described in the previous section.

To allow testing via linear regression, the variable 'Percentage of urbanised area' was first transformed into a parametric equivalent by taking its square root. Furthermore, for the variable 'Urbanisation class', a set of five separate binary variables, also known as dummy variables or indicator variables, was created. This 'dummy coding' was necessary as the original variable was a categorical variable with more than two levels, which requires these additional steps to assure the interpretability of the results of linear regression (Long and Freese, 2006). The analysis permitted computation of the R^2-value and the regression coefficients, indicating how well the perceived urbanisation (urbanisation classes) and the calculated degree of urbanisation (percentage of urbanised area) correspond (see section 3.4.1 for the results).

3.3.5 Correlation analysis visual landscape complexity – degree of urbanisation

In order to find out if complexity varies according to the degree of urbanisation represented by the different landscape types, a correlation analysis and linear regression were performed between the spectral entropy (and thus the complexity of the photographs) and the urbanisation classes. For the correlation analysis, the Spearman correlation coefficient was calculated as the variables were non-parametric (P-value of 0.000 in Shapiro-Wilk test of normality). Again, the five urbanisation classes were used (scores 0-4).

For the linear regression, the variable 'Spectral entropy' was first transformed into a parametric equivalent, specifically in its inverse. Because of the presence of a categorical variable (urbanisation class), the linear regression was again performed using dummy variables, as described in the previous section (3.3.4). The R^2-value and the regression coefficients, obtained from regression, indicate how closely the complexity of the photographs and the represented urbanisation classes are related.

In order to validate the results, this analysis was repeated for the calculated percentage of urbanised area on the photographs (see section 3.4.2 for the results).

3.3.6 Eye-tracking experiment

3.3.6.1 Subjects and stimuli

In total, 42 subjects participated in the eye-tracking test as unpaid volunteers. They were contacted via e-mail to inform them about the experiment but they were not given details concerning the purpose of the study. All participants had normal or corrected-to-normal vision. In order to increase the accuracy of the eye-tracking measurements the participants were asked to wear contact lenses instead of glasses and to forsake mascara.

The stimuli, as described in section 3.3.1, were used to perform the eye-tracking test.

3.3.6.2 Eye-tracking apparatus

The eye-tracking experiment was performed using a fixed RED250-eye tracking device, developed by SMI (Senso Motoric Instruments, Germany). In particular, the eye movements and fixation points of an observer are recorded via the Pupil-Corneal Reflection (P-CR) method (Duchowski, 2007). Fixations are represented by x,y-coordinates of the point-of-regard on the screen as calculated following calibration (Jacob & Karn, 2003; Poole & Ball, 2005). Consequently, the entire gaze pattern consisting of fixations and interconnecting eye movements (saccades) is recorded while observing images on a screen (Poole & Ball, 2005). This allows us to identify which parts of an image catch the attention and which areas are unseen. In this study, a 22-inch colour monitor was used to display the photographs. The eye movement measurement rate was set at 120 Hz. During the experiment, both eyes of the observers were tracked, while the participants were seated at 60 to 80 cm in front of the screen. The seating as well as the monitor could be adjusted to optimize the tracking conditions, which is especially important for obtaining an accurate calibration

(Duchowski, 2007). Finally, the participants were not restricted in their movements by a chin rest, allowing a more natural viewing setting. However, they were kindly asked to avoid making abrupt movements to assure accurate measurements.

The experiment took place in the Eye-tracking Lab of the Department of Geography of the University of Ghent. A laboratory condition was preferred to an experiment in situ as it allows a greater control over the experimental conditions (e.g. light and noise conditions) (Duchowski, 2007). Photographs have been shown to be valid surrogates for real landscapes (Coeterier, 1983; Palmer and Hoffman, 2001).

3.3.6.3 Experiment procedure

Before starting the eye-tracking test participants were given the following instructions (translated from Dutch):

"In this test you will be asked to attentively observe a number of landscape photographs. The entire test consists of 74 photographs, which will be displayed for 10 seconds each. You will not be asked to perform specific tasks, other than observing the images. During the test, your eye movements will be recorded by an eye-tracker, attached under this monitor. Before starting the test, this device will be calibrated. Please try not to move abruptly once this calibration has been performed in order to avoid a recalibration. In total, the eye-tracking test will take approximately 15 minutes, but it is possible to take a break whenever you need it. Please give a sign in advance so that the recording can be stopped on time. After the eye-tracking test, you will be asked to sort the photographs based on their characteristics. You can complete this task at your own pace. All the data obtained during this test will be processed anonymously and will not be used outside this research context. Do not hesitate to ask questions if these instructions are not completely clear to you. Thank you for your cooperation."

Free-viewing was chosen because in real life outdoor landscape observation people look at landscapes freely and without a task in mind (Dupont et al., 2014). In the experiment this condition was reproduced. The photographs were displayed in random order, different for each subject, to avoid order effects in the data.

For the calibration, a 9-dot calibration procedure was used: the participants were asked to fixate nine dots appearing one by one on the screen. By matching the pupil-centre/corneal reflection relationship with the specific x,y-coordinate of the dots, an accurate calibration over the entire screen can be obtained (Goldberg and Wichansky, 2003). This calibration procedure was repeated when deviations from the initial calibration appeared or after a break. Deviations were detected by showing a dot in the centre of a blank screen after each photograph. When the gaze point of the subject deviated from the dot, a new calibration was performed. In addition, this dot provided a consistent starting point for the observation path of each photograph.

During the experiment a number of eye-tracking metrics were calculated such as the number and duration of the fixations. According to Poole and Ball (2005) and Duchowski (2007), a fixation occurs when the eyes are relatively stationary allowing visual perception of information. The lower threshold for determining when a position is stationary, is typically set at 100 milliseconds (Inhoff and Radach, 1998). We followed this recommendation and considered a stationary eye position of at least 100 milliseconds as a fixation. Besides fixations, saccades (eye movements between fixations) were derived as well. We tabulated the number of saccades and their amplitude (degrees) and velocity (degrees/second). Based on fixations and saccades, the entire scan path could be reconstructed and analysed. A scan path is defined as the route of oculomotor events through space within a certain timespan which has a beginning and an end and thus a length (Holmqvist et al., 2011). In other words, it is the distance which an observer 'travels' through an image when observing it. These eye-tracking metrics, calculated from fixations and saccades, allow a detailed analysis and visualisation of the entire observation pattern.

3.3.7 Eye-Tracking Data Processing

3.3.7.1 Analysis of general eye-tracking metrics

In our analysis, we used the following eye-tracking metrics in order to investigate the visual exploration of the landscape photographs: number of fixations, number of saccades and scan path length (px). As only the saccades with an amplitude beyond a certain threshold are useful to examine the viewing pattern, the smaller saccades (microsaccades), which serve to correct for a random drift of the eyes (Cornsweet, 1956) were excluded from the analysis. In particular, all saccades smaller than 0.5 degrees, a threshold strongly defended by Collewijn and Kowler (2008), were deleted. The data was stored in text-files (.txt) by the software of the eye-tracker, which could easily be imported in Excel and SPSS. For each metric, a comparison of means between the five urbanisation classes (Rural, Semi-rural, Mixed, Semi-urban, Urban) was aimed at in order to determine if there is a significant difference in exploration behaviour. This analysis was run for each of the metrics mentioned above. However, as most eye-tracking data is not parametric (Holmqvist et al., 2011) and in this specific study the observations are not independent given that all participants were presented with the same set of photographs of all urbanisation classes, the non-parametric Friedman test was used in combination with post-hoc Wilcoxon Signed Rank tests, in which mean ranks are compared. The Friedman test permits exploring whether the mean rank of the observations in k groups (here the five urbanisation classes) are equal (H_0) or not (H_a). However, no information is provided about which of the groups differ from each other, nor about the magnitude of the difference. Therefore, post-hoc tests were used in which the groups are compared pairwise. Based on the outcome of these Wilcoxon Signed Rank tests, groups of similar and differing mean ranks were detected. The conclusions of the statistical analyses were illustrated by qualitative scan path representations on the original photographs as well as in luminance maps, showing the areas that were observed.

While fixation-, saccade- and scan path metrics are valuable indicators of the general viewing pattern, it is difficult to exactly measure to which extent an image was observed, based solely on the number of fixations and saccades and the scan path length (see Dupont et al., 2015). One could, for example, have a long scan path and a considerable amount of saccades when constantly shifting his/her attention between a very limited number of objects. In this case it could be erroneously concluded that the image has been explored to a large extent while in reality only a small part of the scene has been observed. To resolve this problem, two proxies – the observed vertical area and a Voronoi cell analysis – were used to objectively measure the 'observed area' of an image. Both methods offer the possibility to quantify the 'dispersion of the fixations', which is often referred to when analysing the 'extent' of an observation (Holmqvist et al., 2011). This methodology is described in the next section.

3.3.7.2 Observed vertical area and Voronoi cell analysis

First, we calculated which vertical proportion of the photographs was observed, based on the fixation coordinates and the principle of the minimum bounding rectangle. The observed vertical area was obtained by calculating the difference between the x-coordinate of the highest fixation and the lowest fixation on the image. This derived metric not only provides information about the vertical extent to which an image was observed, but also about its visual exploration as the observation in the horizontal direction has been found to remain constant in equally sized landscape photographs (Dupont et al., 2014).

This analysis was extended by applying the Voronoi method in accordance with Over et al. (2006). More specifically, for each fixation one cell was calculated and drawn, based on a set of points in space whose distance to the given fixations is smaller than their distance to any other fixation. In order to avoid border effects, in particular the occurrence of larger Voronoi cells for fixations along the border, the minimum bounding polygon (convex hull) containing all fixations was first calculated. The Voronoi cells were then calculated within the area of the convex hull. Images in which fixations are clustered, will generate small Voronoi cells, while a dispersed fixation pattern will result in large Voronoi cells. In this study, we compared the areas of the

Voronoi cells of each participant in each of the five urbanisation classes in order to assess the extent to which these scenes are visually explored.

For both proxies, a Friedman and Wilcoxon Signed Rank test were performed (P-value of 0.000 in Kolmogorov-Smirnov test of normality) to detect significant differences between the five urbanisation classes, with the null hypothesis stating that there are no differences between the groups.

3.4 RESULTS

3.4.1 Correlation urbanisation classes and percentage of urbanised area

Figure 3.2 shows the mean percentage of urbanised area, as calculated from the photographs. The graph clearly indicates a gradual increase in this percentage from rural to urban landscapes. The Spearman correlation coefficient and R^2-value of the linear regression confirm a strong positive correlation between the urbanisation classes and the percentage of urbanised area, with values of 0.959 ($P < 0.001$) and 0.962 ($P < 0.001$) respectively. As a result, the perceived degree of urbanisation is in accordance with the measured urbanised area. This means that the urbanisation classes obtained by the participants' sorting are valid and can thus be used for further analyses.

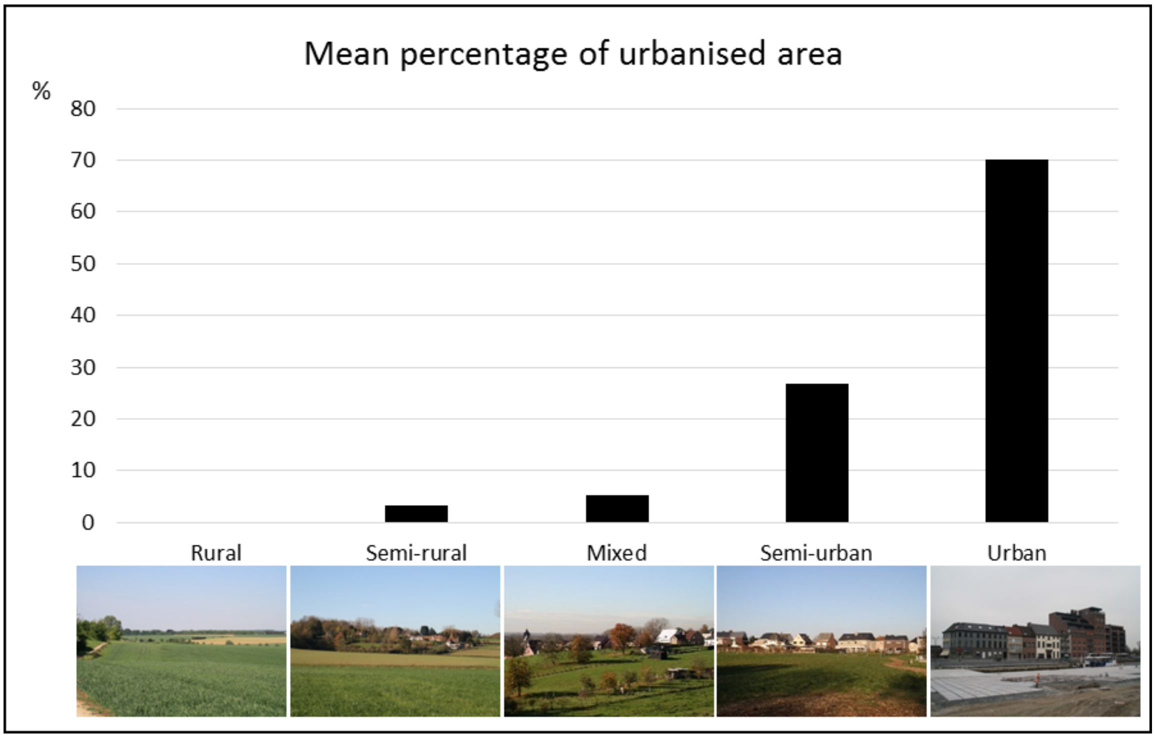

Figure 3.2 Mean percentage of urbanised area in the photographs per urbanisation class.

3.4.2 Correlation of visual landscape complexity and degree of urbanisation

The Spearman correlation coefficient yielded a value of 0.875 ($P < 0.001$), indicating a strong positive correlation between spectral entropy and the urbanisation classes.

The linear regression produced an R^2 value of 0.815 ($P < 0.001$). Thus, the urbanisation class explains 81.5% of the variation in spectral entropy. The regression coefficients indicate that the spectral entropy - and thus the image complexity - increases with increasing urbanisation classes (0-4) represented in the five landscape types. In other words, the five urbanisation classes can be arranged in terms of increasing visual complexity as follows: Rural < Semi-rural < Mixed < Semi-urban < Urban (see Figure 3.3).

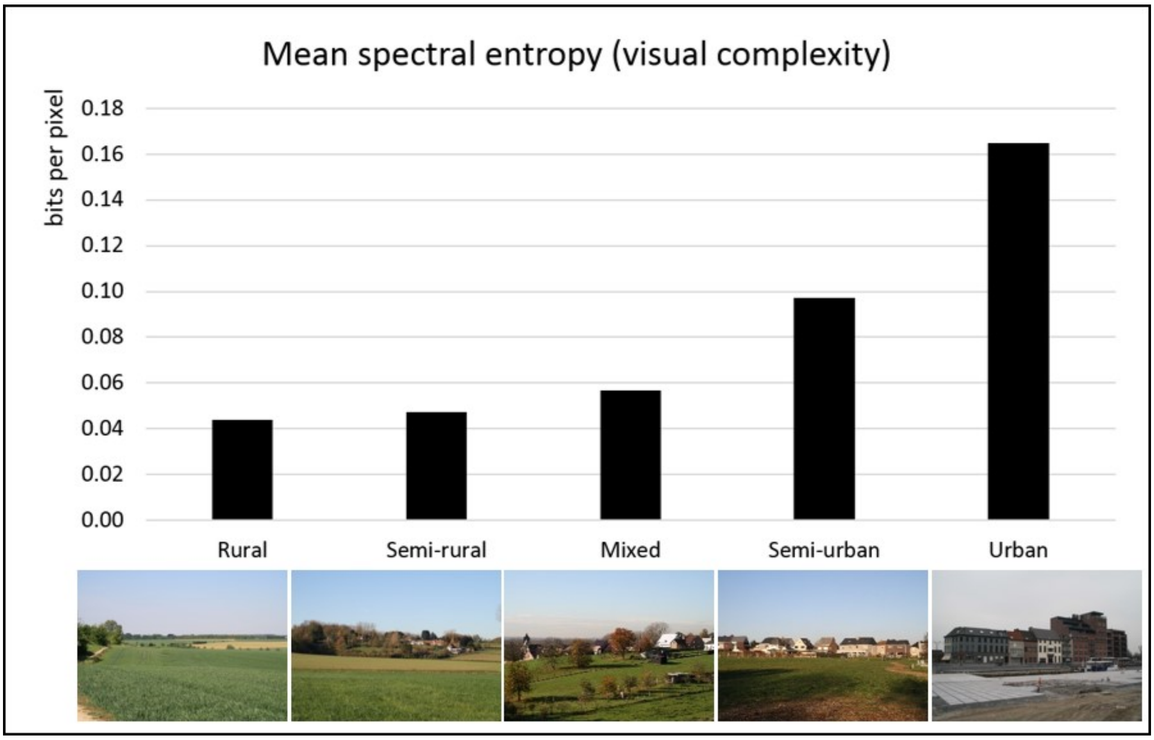

Figure 3.3 Mean spectral entropy value per urbanisation class, indicating the visual complexity of the landscape photographs.

A similar correlation was found between the spectral entropy and the percentage of urbanised area. The Spearman correlation analysis generated a value of 0.837 ($P < 0.001$), while the linear regression yielded an R^2-value of 0.703 ($P < 0.001$). This indicates that the urbanisation classes can be used to represent different gradients of visual landscape complexity.

3.4.3 Viewing Patterns in Different Urbanisation Classes, Varying in Complexity

3.4.3.1 General characteristics of the viewing pattern

Table 3.1 provides an overview of the eye-tracking metrics for each urbanisation class. The colours indicate the results of the pairwise Wilcoxon Signed Rank test. Each colour represents a group of similar means (no significant difference found): turquoise =

lowest mean rank, green = medium mean rank, yellow = highest mean rank. N is the number of observations, s is the standard deviation.

For the number of fixations, the Wilcoxon Signed Rank test identified three groups of similar means: rural/semi-rural/mixed landscapes, semi-urban landscapes and urban landscapes (Table 3.1). In particular, rural, semi-rural and mixed landscapes seem to be characterized by significantly fewer fixations ($P < 0.001$), whereas this number is higher in semi-urban and higher still in urban landscapes ($P < 0.001$) (Table 3.1).

Table 3.1 Mean ranks based on the outcome of the Friedman test, colours indicate the result of the Wilcoxon Signed Rank test.

Eye-tracking metric	N	Chi-Square	df	Mean rank per urbanisation class					P	Real mean values				
				Rural	Semi-rural	Mixed	Semi-urban	Urban		Rural	Semi-rural	Mixed	Semi-urban	Urban
Number of fixations	42	39.654	4	2.85	2.39	2.24	3.44	4.08	5.1E-8	31.89 (s = 3.21)	31.40 (s = 2.98)	31.36 (s = 2.71)	32.41 (s = 2.72)	33.31 (s = 2.70)
Number of saccades	42	44.706	4	3.51	2.48	2.03	2.94	4.06	4.6E-9	24.78 (s = 3.81)	23.74 (s = 3.16)	23.32 (s = 3.18)	24.25 (s = 3.36)	25.57 (s = 3.51)
Scan path length	42	51.276	4	4.14	1.90	2.57	2.81	3.57	2.0E-10	6,914.09 (s = 1,569.33)	6,133.46 (s = 1,298.65)	6,331.63 (s = 1,393.54)	6,432.69 (s = 1,163.65)	6,690.24 (s = 1,430.52)

While the number of fixations and saccades are inherently correlated (Poole and Ball, 2005), especially the number of saccades (microsaccades excluded) can be considered as an indicator of how extensively an image has been inspected (Goldberg and Kotval, 1999). Significant differences were found between the following three groups ($P < 0.001$): rural/urban landscapes, semi-rural/mixed landscapes and semi-urban landscapes (Table 3.1). Our experiment thus points out that highly urbanised landscapes (semi-urban and urban) seem to elicit extensive visual exploration. The opposite occurs in landscapes characterized by a limited amount of buildings (semi-rural and mixed), in which the visual exploration is weaker. While an increasing number of fixations and saccades is found when the degree of urbanisation increases, this trend cannot be applied to rural landscapes, as these landscapes would then be expected to generate the smallest amount of fixations and saccades. This is not the case. Although the difference with semi-rural or mixed landscapes is not always significant according to the statistical tests (see number of fixations), the number of both, fixations and saccades, in rural landscapes appears to be higher than what would be expected (Table 3.1). In Figure 3.4 (section a and b), the mean rank of the number of fixations and saccades is plotted against the visual complexity (given by the mean spectral entropy) of each urbanisation class. The ranks are the result of the Friedman test, the colours indicate the outcome of the Wilcoxon Signed Rank test. Each colour represents a group of similar means (no significant difference found): turquoise = lowest mean rank, green = medium mean rank and yellow = highest mean rank. The mean spectral entropy was plotted as well to indicate the degree of visual complexity of each urbanisation class. For visualisation purposes the spectral entropy values were multiplied by a factor 10. The graph shows that the number of fixations and saccades, and thus the visual exploration, seems to increase in more complex landscape photographs. Rural landscapes do not seem to follow this trend as the number of fixations and saccades is higher than what would be expected based on the low complexity of this kind of landscapes. In other words, low-complexity rural landscapes seem to be visually explored more extensively than expected.

Another eye-tracking metric that contains valuable information about the extent to which an image has been explored, is the scan path length, as it comprises the entire 'travel distance' made by an observer (Holmqvist et al., 2011). The statistics concerning the scan path length exhibit a similar pattern as the number of fixations and saccades. In semi-rural and mixed (and to a lesser extent semi-urban) landscapes the scan path seems to be the shortest, while the longest scan paths occur in rural and urban landscapes ($P < 0.001$) (Table 3.1). This suggests that visual exploration of scenes, characterised by a low built content (semi-rural, mixed and semi-urban), is less extensive compared to completely urban or rural scenes, in which the visual exploration is maximized. Rural landscapes again produce unexpected results as a much weaker visual exploration would be expected based on the low complexity of this kind of landscape. Figure 3.4 (section c) illustrates these results. Besides the groups of similar means, the graph also shows a longer scan path, and thus a more extensive visual exploration, when the visual complexity of the landscape increases. In this respect, the pattern found for rural landscapes can again be labelled as unexpected.

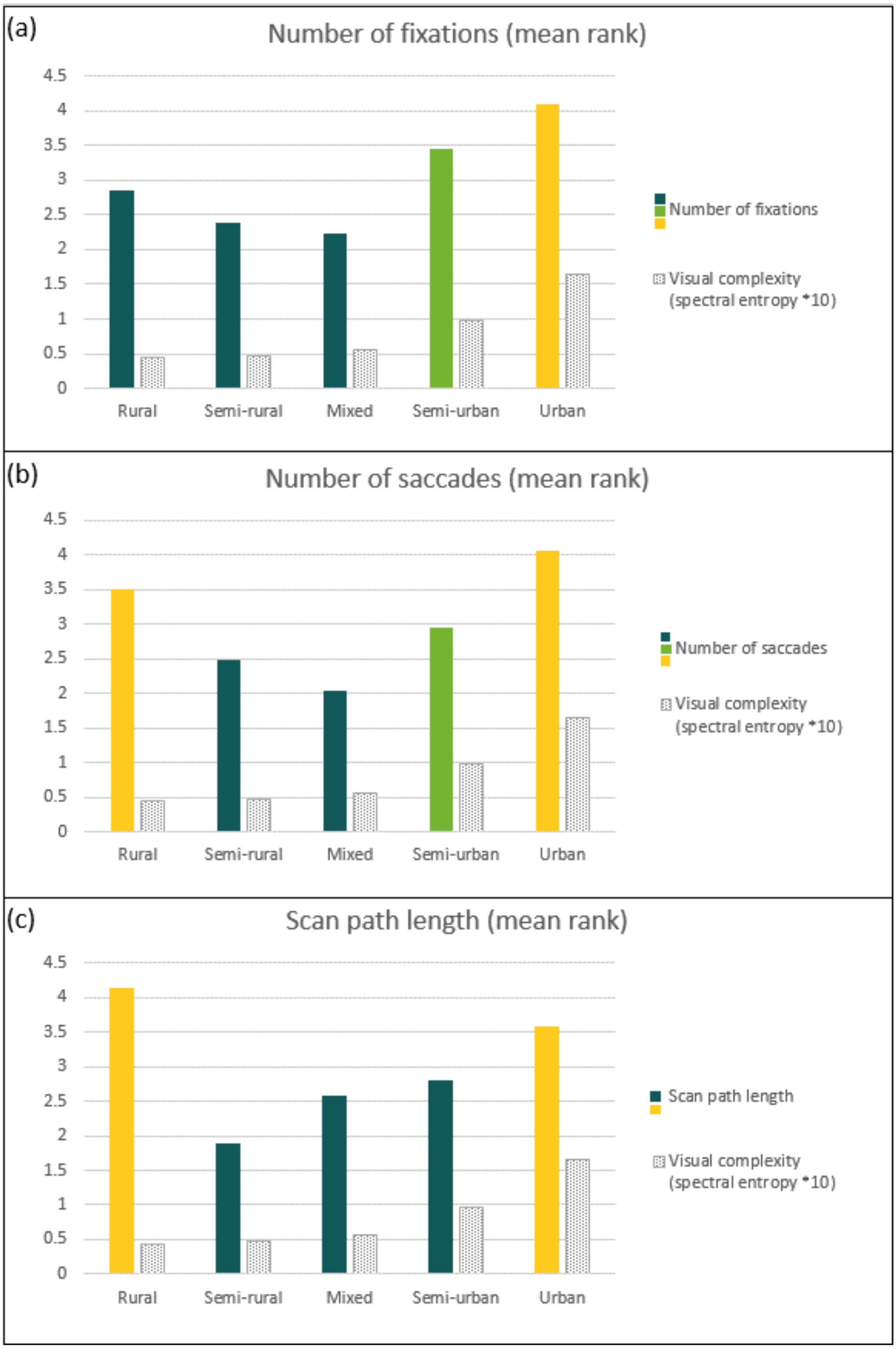

Figure 3.4 Results of the Friedman and Wilcoxon Signed Rank test for the eye-tracking metrics. (a) Mean rank of the number of fixations per urbanisation class, (b) Mean rank of the number of saccades per urbanisation class, (c) Mean rank of the scan path length per urbanisation class.

3.4.3.2 Extent of the visual exploration

Table 3.2 summarizes the results of the observed vertical area and the Voronoi cell area analysis. The colours indicate the results of the pairwise Wilcoxon Signed Rank test. Each colour represents a group of similar means (no significant difference found): turquoise = lowest mean rank, green = medium mean rank, yellow = highest mean rank. N is the number of observations, s is the standard deviation.

The Wilcoxon Signed Rank test reveals that the observed vertical area is largest in urban and rural landscapes, followed by semi-urban landscapes, and reaches a minimum in mixed and semi-rural landscapes. This means that there seems to be an increase in the observed vertical area when the degree of urbanisation increases, indicating a more extensive visual exploration in more urbanised landscapes. Rural landscapes again do not fit this trend as the vertical proportion that is observed in these scenes seems to be larger than expected.

In the graphs in Figure 3.5 (section a), the mean rank of the observed vertical area is plotted against the visual complexity (expressed by the mean spectral entropy) of the urbanisation classes. The ranks represented in the graphs are the result of the Friedman test, the colours indicate the outcome of the Wilcoxon Signed Rank test. Each colour represents a groups of similar means (no significant difference found): turquoise = lowest mean rank, green = medium mean rank, yellow = highest mean rank. For visualisation purposes the spectral entropy values were multiplied by a factor 10. For the observed vertical area, the graph shows increasing values with increasing visual landscape complexity. More complex landscapes thus seem to elicit a larger vertical exploration indicating a more extensive visual exploration. The graph also clearly shows the inconsistency between the large observed vertical area and the low visual complexity of rural landscapes, suggesting an unexpectedly extensive visual exploration of these rather simple landscapes.

Table 3.2 Mean ranks based on the outcome of the Friedman test for the observed vertical area and Voronoi cell area analyses. Colours indicate the result of the Wilcoxon Signed Rank test. Measured mean values are given for each urbanisation class.

	N	Chi-Square	df	Mean rank per urbanisation class					P	Real mean values				
				Rural	Semi-rural	Mixed	Semi-urban	Urban		Rural	Semi-rural	Mixed	Semi-urban	Urban
Observed vertical area	42	106.038	4	3.81	1.55	1.83	3.38	4.43	5.1E-22	549.52 (s = 102.86)	421.73 (s = 104.45)	454.30 (s = 84.33)	536.63 (s = 80.13)	599.76 (s = 101.67)
Voronoi cell area	42	50.076	4	3.88	1.62	2.88	3.10	3.52	3.5E-10	3,417.56 (s = 553.05)	2,662.30 (s = 604.77)	3,065.51 (s = 565.32)	3,158.93 (s = 486.18)	3,285.56 (s = 591.82)

A similar pattern emerges from the Voronoi analysis (Table 3.2). In particular, the cell area seems to be smallest in semi-rural landscapes and increases gradually over mixed and semi-urban landscapes to reach a maximum value in urban landscapes (apart from the rural category). This means that the fixation pattern gets more dispersed when the degree of urbanisation increases. As a consequence, the observed proportion of the landscape photograph – and thus its visual exploration – becomes larger when a landscape is more urbanised. While the fixations are rather clustered in landscapes with only a limited number of buildings (semi-rural), they are much more dispersed in landscapes almost solely consisting of buildings (urban). Rural landscapes again do not seem to follow the general trend: instead of generating the smallest Voronoi cell areas and thus eliciting the weakest visual exploration, rural landscapes seem to be characterised by the largest Voronoi cell areas. As a result, the fixation pattern in these landscapes is much more dispersed than what would be expected. Consequently, a more extensive visual exploration behaviour is found in this type of landscape. Figure 3.5 (section b) combines the mean rank of the Voronoi cell area with the visual complexity (i.e. mean spectral entropy) of each urbanisation class. The colours again represent the groups of similar means detected by the Wilcoxon Signed Rank test. For visualisation purposes the spectral entropy values were multiplied by a factor 10. The graph demonstrates that the Voronoi cells become larger with increasing visual landscape complexity. In addition, the unexpectedly large Voronoi cell areas in rural landscapes again appear. The conclusions made based on the analysis of the observed vertical area are thus supported by the Voronoi analysis.

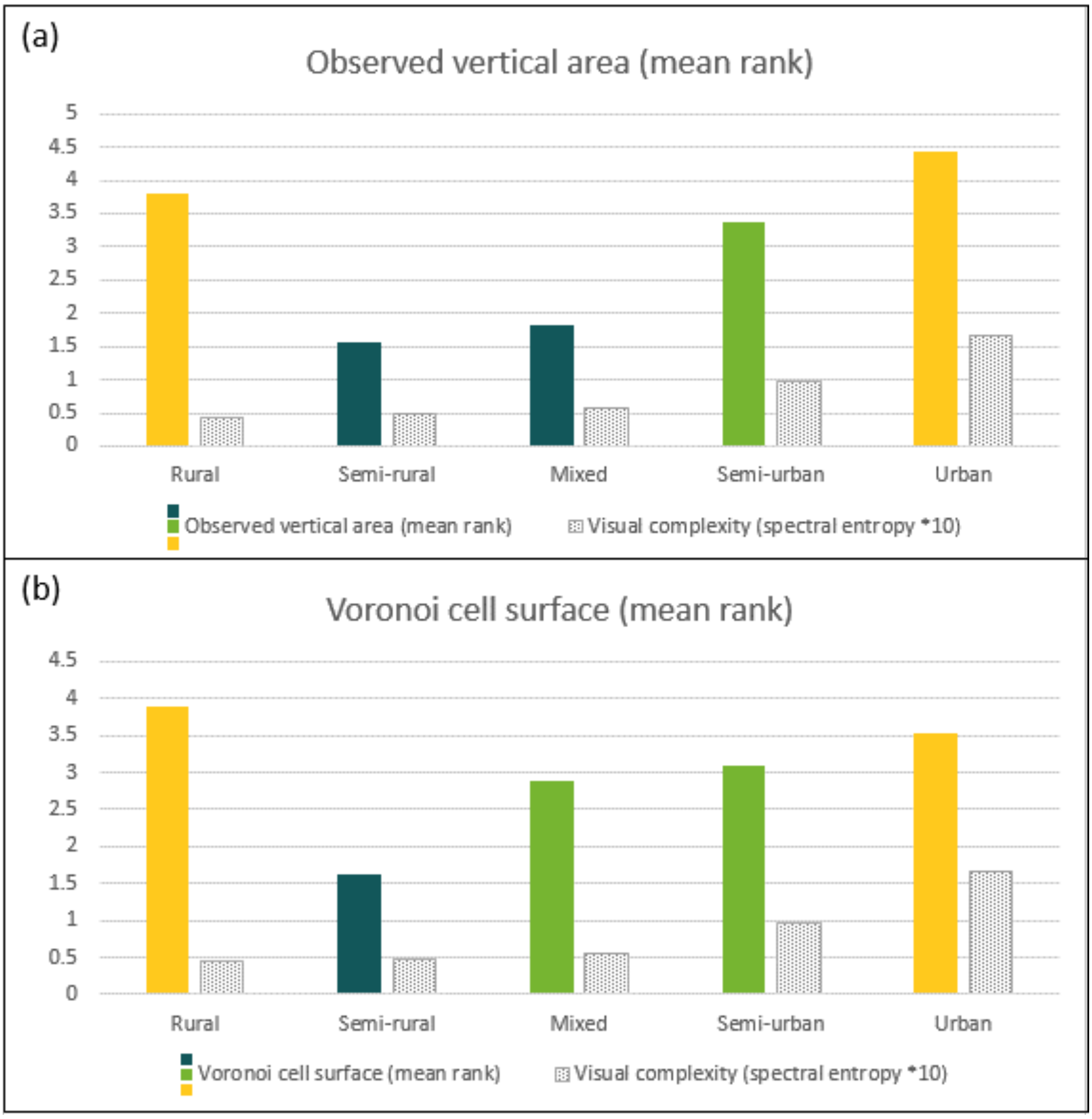

Figure 3.5 Results of the Friedman and Wilcoxon Signed Rank test for the observed vertical area and Voronoi cell area. (a) Mean rank of the observed vertical area per urbanisation class, (b) Mean rank of the Voronoi cell area per urbanisation class.

The trend of increasing visual exploration with increasing visual complexity of the landscape image is confirmed by the Pearson's correlation coefficients calculated between the eye-tracking metrics (number of fixations, number of saccades, scan path length, observed vertical area and Voronoi cell area) and the visual landscape complexity, represented by the inverse function of the spectral entropy (parametric equivalent of the spectral entropy). The results are presented in Table 3.3. Rural landscapes do not follow this linear trend as, for all metrics, the values seems to be higher than expected based on the low complexity of this kind of landscapes. This indicates a more extensive exploration than what would be predicted. As a consequence, the rural category of images was not included when calculating the correlation coefficients. Only observations for the semi-rural, mixed, semi-urban and urban classes were considered in this analysis. For all metrics, medium to strong negative (because of the inverse function) coefficients were found. All were significant ($P < 0.05$) to highly significant ($P < 0.01$) (Table 3.3). These results confirm the findings of the analysis performed on the different urbanisation classes as they also indicate an increase in visual exploration when the visual complexity of the landscape image increases.

Table 3.3 Pearson's correlation coefficients calculated between the eye-tracking metrics and the inverse function of the spectral entropy.

	N	Pearson's correlation coefficient
Number of fixations – inverse(spectral entropy)	40	-0.522**
Number of saccades – inverse(spectral entropy)	40	-0.504**
Scan path length – inverse(spectral entropy)	40	-0.369*
Observed vertical area – inverse(spectral entropy)	40	-0.768**
Voronoi cell area – inverse(spectral entropy)	40	-0.701**

**correlation is significant at the 0.01 level
* correlation is significant at the 0.05 level

Figure 3.6 illustrates the results of the analyses by providing scan paths (first column), luminance maps (second column), visualisations of the observed vertical area (third column) and Voronoi cell representations (fourth column) for each urbanisation class. In the scan path visualisations, the dots represent fixations, interconnecting lines are saccades. On the luminance maps, the highlighted parts are the areas that received attention by the observer; the dark parts were not observed. The observed vertical area was indicated on luminance maps with a maximum kernel width. The Voronoi cells are represented as calculated within the convex hull containing all fixations. The visualisations are all based on an entire 10 second trial. The scan path visualisations show the shorter scan paths and the lower number of fixations in semi-rural (b) and mixed (c) landscapes, compared to semi-urban (d), rural (a) and urban landscapes (e). The luminance maps visualise the exploration pattern of the images, showing a more extensive visual exploration of the rural, semi-urban and urban scenes (more dispersed fixation pattern). In semi-rural and mixed landscapes the exploration is much more constrained (clustered fixation pattern). This pattern is also reflected in the illustrations of the observed vertical area and Voronoi cells. The arrows representing the observed vertical area and the Voronoi cell area tend to increase with increasing urbanisation, with rural landscapes bucking this trend.

Figure 3.6 Scan path visualisations for one observer (first column) and their corresponding luminance maps (second column), visualisations of the observed vertical area (third column) and Voronoi cell representations (last column) for each urbanisation class: (a) Rural, (b) Semi-rural, (c) Mixed, (d) Semi-urban and (e) Urban landscapes.

3.5 DISCUSSION

3.5.1 Degree of urbanisation and visual exploration

Kaplan and Kaplan (1989) state that the visual exploration of landscapes is clearly linked with the structure of the landscape. Our results agree with this statement, as we observed different exploration patterns depending on the degree of urbanisation of the landscape, a property contributing to its structure. Apparently, weakly urbanised landscapes (semi-rural and mixed landscapes) seem to constrain its visual exploration. As these landscapes are characterised by a limited number of buildings it is probable that these buildings act like eye-catchers. This is in line with earlier findings by Dupont et al. (2015), who demonstrated that a few buildings situated in a green environment – similar to the semi-urban and mixed landscapes tested here – seem to catch a lot of attention. As a result, a considerable proportion of the attention will be clustered on buildings instead of being spread over other aspects of the landscape, which may explain the more restricted visual exploration observed in these landscapes. In strongly urbanised landscapes, this phenomenon reverses when the amount of built area in the photograph reaches a threshold, from which the built area becomes so elevated that it no longer acts as an eye-catcher because a too large proportion of the image consist of buildings. This elicits a more dispersed visual exploration in semi-urban and urban landscapes. In this study we did not pursue estimation of this threshold, but potentially there is a change that it might be related to the percolation threshold of 0.59 (Stauffer, 1985), where its validity has been demonstrated in landscape ecology studies in which landscape patterns are analysed (e.g. Oliveira de Filho and Metzger, 2006; Ritters et al., 2007). However, further research is necessary to confirm this relationship.

3.5.2 Complexity and visual exploration

In 1963, Berlyne found that high-complexity stimuli elicit a greater amount of exploratory behaviour than low-complexity images. This was particularly true for abstract pattern images. Wohlwill (1968), however, investigated how the complexity of images from the real environment influences the amount of exploratory activity. This activity seemed to monotonically increase as complexity increases, suggesting a more comprehensive exploration in more complex environmental images. Our results are consistent with this conclusion for the most part as the eye-tracking experiment shows that the visual exploration expands with increasing image complexity. This means that the degree of variation and diversity of a landscape photograph affects the viewing pattern. More specifically, the larger the variation in an image, the more different things there are to look at, the larger the amount of information to be processed by the observer (Wohlwill, 1968; Kaplan and Kaplan, 1989) and the larger the interest-value of the stimulus (Berlyne, 1963; Day, 1967). As a result, high-information (complex) images could elicit a more extensive visual exploration behaviour as people try to assimilate as much of the presented information as possible. This explains the higher number of fixations and saccades, the longer scan paths and the larger observed vertical area and Voronoi cell areas in the more complex landscapes tested in this study. On the landscape level, these results could be explained by the notion that people, when observing landscapes freely and unrestrictedly, usually seem to search for resources present in a landscape (de la Fuente de Val et al., 2006). While simple environments are considered to have only few resources, more complex landscapes could have so many of them that locating and assimilating them requires more effort (Orians, 1986). This could explain the more exhaustive visual exploration patterns in these kinds of landscapes.

While our study falls mostly in line with earlier work, one part of the results appears to be novel: the most simple landscape category in terms of spectral entropy (rural landscapes) does not seem to bring about the weakest visual exploration as what would have been expected based on earlier findings (e.g. Berlyne, 1963; Wohlwill, 1968). Instead, these landscapes seem to elicit a more extensive visual exploration, comparable with the most complex landscapes tested in this study. We speculate that this could be a result of the monotonous character of these landscapes as they do not exceed in variation and thus do not contain much information. According to Klinger and Salingaros (1998) and Stamps (2002) stimuli with low information content are often experienced as boring. As a consequence, it is possible that people start looking around in search of interesting objects. This also fits in the context of resources, as suggested by Orians (1986). Since resources are scarce in simple environments, people could start searching for them, which would explain the more extensive visual exploration behaviour in uncomplicated rural landscapes. another speculation which might explain our results is that people, given an image that does not have much to offer visually, start ‘making up’ their own task to stay busy and, as a consequence, explore the image more extensively. This could especially be the case in this study since there was a fixed viewing time of 10 seconds, during which the images needed to be observed. As participants were not able to self-terminate the photographs and switch to the next one, but instead were forced to view each photograph for 10 seconds, this might have been too long in the ‘boring’ rural scenes, giving rise to ‘task-self-creation’. More research should be done in order to find out why rural landscapes elicit an unexpected viewing behaviour, for example, by gaining insight into participants’ thoughts and cognitive processes while viewing the images. This can be done either after the experiment using a questionnaire, or during the experiment by applying the ‘thinking aloud’-method, in which participants are asked to say out loud what crosses their mind while observing the images (Nielsen, 1993; Van Someren et al., 1994).

3.6 CONCLUSIONS

The purpose of the study was to analyse if the visual exploration of landscape photographs depends on the type of landscape represented in the image. We also investigated if there is a relationship between the degree of urbanisation and the visual complexity of the landscape in order to find out if differences in the viewing patterns could be explained by differences in visual complexity of the landscape images. The results indicate that the degree of urbanisation represented in landscape photographs as visually classified by the participants corresponds to the visual image complexity as measured by the spectral entropy. The eye-tracking experiment points out that people seem to observe landscapes of distinct urbanisation level in different ways. In particular, an increase in visual exploration and a more dispersed viewing pattern were observed when the degree of urbanisation of a landscape increased. As the urbanisation level appears to be positively correlated with the visual complexity of a landscape photograph, it can be concluded that increasing visual complexity of a landscape photograph enhances its visual exploration and generates a more dispersed fixation pattern. This can be the result of a larger degree of variation, and thus the larger amount of information present in more complex landscape photographs. In an attempt to assimilate as much information as possible, people could exhibit a more extensive visual exploration. One type of landscape was found to stand out as an exception. In rural landscapes, the viewing pattern was namely more dispersed than what would be expected from their low visual complexity. More specifically, more extensive visual exploration almost as extensive as in urban landscapes was observed in rural landscapes. We speculate that this is related to the observation that, as a result of the low degree of variation and the low information content in this kind of landscape, people get bored and start looking around in the photograph in order to try to find elements of interest.

While our study provides primary insight into the visual exploration behaviour over landscapes of different complexity, this research could be extended in order to investigate how the results of this study and eye-tracking in general might be useful for landscape assessment processes, in which complexity plays an important role. What one sees and how one sees it, is likely to influence how one thinks about it and thus how one evaluates it.

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CHAPTER 4: DOES LANDSCAPE RELATED EXPERTISE INFLUENCE THE VISUAL PERCEPTION OF LANDSCAPE PHOTOGRAPHS? IMPLICATIONS FOR PARTICIPATORY LANDSCAPE PLANNING AND MANAGEMENT

Modified from:

Dupont, L., Antrop, M., Van Eetvelde, V. (2015). Does landscape related expertise influence the visual perception of landscape photographs? Implications for participatory landscape planning and management. Landscape and Urban Planning, 141, 68-77.

ABSTRACT Does expertise in landscape related issues influence the way landscapes are observed? In an eye-tracking experiment 21 landscape experts and 21 laymen were asked to observe 74 landscape photographs, each for 10 s. Experts seemed to make significantly more fixations and saccades, had a longer scan path and a larger visual span than the laymen. As a consequence, in the same amount of time, experts visually explored the landscape photographs to a wider extent and in a more global and holistic fashion. This is probably due to the presence of expertise, which seemed to enhance efficient information extraction, enabling experts to interpret and understand the landscapes more easily. In contrast, the laymen's visual exploration of the landscapes was considerably more restricted as they spent significantly more time and attention to singular objects, in particular to buildings. This behaviour may be a result of the lack of expertise, which makes longer fixation times necessary to understand the meaning of the composing landscape elements. A slower information processing leaves less time to visually explore the landscape photograph and hampers laymen to observe the landscape as a whole. Consequently, experts and laymen may not perceive the same features in a landscape and might not even see the same landscape. This conclusion is important for participatory landscape management in which experts and laymen are asked to visually assess landscapes. The often diverging assessments of both groups

could partially be explained by their literally different view on landscapes, on which their judgement is based.

KEYWORDS: Eye-tracking, landscape perception, distribution of attention, information processing, scan path, visual landscape assessment

4.1 INTRODUCTION

Landscapes are important in our every-day activities and their condition affects our quality of life. Consequently, people are concerned when these landscapes are subject to change (Scott and Moore-Colyer, 2005). However, landscape management and development policies are often very top-down driven. Strategies are formulated by experts while the opinion of the public is insufficiently considered (Harrison and Burgess, 2000; Luz, 2000; Pinto-Correia et al., 2006). As a reaction, an increasing number of researchers express the need to incorporate public perception approaches in landscape management processes, as it is the public who eventually will experience the new developments (Seddon, 1986; Nassauer, 1997; De Groot, 2006; Vouligny et al., 2009). This participatory methodology is also strongly promoted by the European Landscape Convention (Council of Europe, 2000) and the Aarhus Convention (UNECE, 1998).

Landscape change essentially affects the visual aspect of the landscape and policy makers usually seek to limit this impact (Dakin, 2003; Gobster et al., 2007). A widely used method to evaluate landscape management and development consists of using landscape photographs and simulations. This technique also seems particularly effective in informing a lay public about landscape changes (Tress and Tress, 2002; Bishop and Rohrmann, 2003; Ryan, 2006) and is therefore increasingly gaining importance in landscape management and design (Al-Kodmany, 1999; Lange, 2005). Landscape visualisations have, for example, been used for assessing environmental management planning (e.g. Sheppard and Meitner, 2005), for evaluating the visual impact of wind turbines (e.g. Thayer and Freeman, 1987; Lothian, 2008; Tsoutsos et al., 2009; Del Carmen Torres Sibille et al., 2009; De Vries et al., 2012) and for assessing landscape management in general (e.g. Dandy and Van Der Wal, 2011). However, although visualizations could facilitate the dialogue between policymakers, planners and designers (experts) and the general public (non-experts) (Lange, 2005), often both groups seem to have opposed views when it comes to evaluating landscape changes visually (Godschalk and Paterson, 1999; Bell, 2001). These differences may be related to the way people literally perceive their environment. Research has demonstrated that the same landscape may indeed elicit different perceptions by different people (Brabyn, 1996; Conrad et al., 2009). This could be a result of the fact that not everyone observes a landscape in the same way and thus that different persons do not necessarily see the same landscape. As a result, different groups of observers may also perceive different features as being the key aspect of a specific landscape. In particular, this could be an issue in visual landscape assessment studies based on landscape photographs in which different groups of observers are consulted. If those groups indeed observe landscapes differently, the probability of having diverging opinions increases as different people might literally not see the same landscape. However, research on how landscape visualizations are perceived is still underexplored (Lange, 2005), while this could perhaps explain the discord between landscape experts and lay people when it comes to visual landscape assessments. In this context, Sevenant (2010) reports that perception is selective and intelligent, which is illustrated by the statement 'you see what you know or recognize'. Differences in people's intellectual and/or social background, related to acquired knowledge, experience, culture, ethnicity et cetera, will influence what is known, what will be recognized and thus what will be seen. In-depth analysis of how persons with different backgrounds observe landscape(s) (photographs) could be very useful in better understanding how disagreements between landscape experts and lay people concerning visual landscape aspects arise. This information could also help to more easily resolve such issues.

In this study, we analyse if landscape experts, who acquired knowledge and (professional) expertise in landscape related topics, indeed observe landscapes differently from the general public and how this is reflected. To this end, we conducted an eye-tracking experiment, in which landscape experts and laymen were asked to observe a number of landscape photographs. During the experiment, the observer's point of regard, as well as the direction of his/her eye movements (or saccades) were continuously recorded. These data subsequently allow a complete reconstruction and analysis of the gaze pattern made while observing the landscape photographs. The first research objective is related to the hypothesis that the global viewing pattern differs between landscape experts and laymen. It is expected that experts visually explore a landscape differently from lay people because of their expertise in landscape related issues. This is investigated in this paper. The second research objective is to determine on which elements in a landscape experts and lay people fix their attention and if significant differences between both groups exist. To explore this, we perform statistical analyses, as well as a qualitative examination of the eye-tracking data. Comparing image perception of experts and novices has been applied in many eye-tracking studies in several domains of interest. Examples are given by Landsdale et al. (2010) (experienced versus untrained users of aerial photographs), Hermans and Laarni (2003) (experienced versus novice map users), Mourant and Rockwell (1972), Underwood (2007) and Konstantopoulos (2009) (advanced versus novice drivers), Krupinski (1996) and Litchfield et al. (2008) (experienced versus inexperienced radiologists), Mann et al. (2007) and Cañal-Bruland et al. (2011) (professional sportsmen versus novices), Reingold et al. (2001) (professional chess players versus novices), Nodine et al. (1993) and Vogt and Magnussen (2007) (artists versus artistically untrained participants) etc. All of these studies found significant differences between the observation patterns of experts and novices. However, in landscape research, eye-tracking is a relatively new technology. Except for the studies of De Lucio et al. (1996) (analysis of the exploration strategies of men and women in natural landscapes), Berto et al. (2008) (analysis of the types of attention when viewing landscape photographs), Tveit et al. (2010) (investigation of which aspects of a landscape are important when assessing its stewardship), Nordh et al. (2012) (analysis of eye movement patterns when rating restoration likelihood while viewing landscape photographs) and Dupont et al. (2014) (analysis of how photographs properties and landscape characteristics affect the viewing pattern) this technology has been little used in this field so far.

4.2 METHODS

4.2.1 Subjects

Two groups of 21 subjects each participated in the eye-tracking experiment. The expertise groups were formed based on the educational and/or professional background of the subjects, by analogy with previous studies concerned with expert-novice differences (e.g. Hermans and Laarni, 2003; Dyer et al., 2006; Vogt and Magnussen, 2007; Konstantopoulos, 2009; North et al., 2009 etc.). Participants who are actively working or studying in landscape related fields were assigned to the 'landscape expert' group. Subjects without such educational or professional background were assigned to the 'laymen'-group. In practice, the expert group consisted of landscape researchers, landscape ecologists, landscape architects and planners and students who were finishing a Master in Geography with a specialisation in Landscape Research. For the laymen group subjects who were unfamiliar with landscape related topics were chosen. In total, 42 persons (18 males and 24 females), aged between 22 and 65 and naive with respect to the purpose of the study, voluntary participated in the experiment. All subjects had normal or corrected-to-normal vision.

4.2.2 Photograph stimuli

In total, 74 colour photographs, representing a variety of rural and more urbanised landscapes in Belgium and northern France were used as stimuli. A range of different most common landscape types was chosen in order to be able to generalise the results of the study (for Belgium and the north of France) as much as possible. Figure 4.1 gives an idea of the landscapes included in the study. All photographs were taken with a constant focal length of 50mm using a tripod to assure a constant shot height (1.70m). All images subtended 31° (width) x 21° (height) of visual angle.

Landscape photographs were used as stimuli for several reasons. First, we used a non-portable eye tracker, which excluded performing the experiment in situ. Moreover, taking the participants to the physical environment itself has many limitations, in particular in controlling the settings of the experiment. Second, numerous studies have demonstrated photographs to be valid surrogates for real landscapes (Shafer and Richards, 1974; Shuttleworth, 1980; Coeterier, 1983; Zube et al., 1987; Palmer and Hoffman, 2001). We thus assume that eye-tracking results based on photographs are similar to tracking results obtained in the real world.

Figure 4.1 Examples of the landscape photographs used in the eye-tracking experiment.

4.2.3 Eye-tracking apparatus

The eye-tracking data were measured by a non-portable RED-eye-tracking system, developed by SMI (Senso Motoric Instruments, Germany). Eye-tracking technology is based upon low power infrared light, which is sent into and reflected by the eyes of the observer. From this reflected signal the precise x,y-coordinates of the observer's point-of-regard is calculated (Jacob and Karn, 2003; Poole and Ball, 2005). As a result, this technology allows a continuous registration of the observer's fixation point while observing images displayed on a 22-inch colour monitor at a screen resolution of 1280 x 1025 pixels. The RED-system uses a measurement rate of 120 Hz, meaning that the gaze direction is recorded 120 times per second. Consequently, the entire gaze pattern, consisting of fixations and interconnecting eye movements or saccades can be reconstructed (Poole and Ball, 2005). Furthermore, it is also possible to detect the centres of attention in the images, which are the areas in the image that drew most attention. Unlike some other eye-tracking systems, the RED-system records both eyes. This offers the advantage of having back-up data of the second eye when for some reason the data of the right eye (usually used) turns out to be unusable. Furthermore, no chin rest is used. The observer is not restricted in his/her movements, which contributes to the participant's comfort. However, subjects were asked not to move too brusquely, but make themselves comfortable in a static pose to avoid imprecise or erroneous measurements. The seating and monitor were adjusted in a way that the eyes were approximately in the middle of the screen, creating optimal tracking conditions for both eyes.

4.2.4 Procedure

The experiment was run in individual sessions of approximately 20 minutes and took place during six days in May 2012 in the Eye-tracking Lab of the Department of Geography at the University of Ghent. At the beginning of the experiment, participants were asked to complete a questionnaire concerning personal information, including background information like education. The test consisted of free-viewing the 74 landscape photographs, each displayed for 10 seconds. Free-viewing means that the participants were not given an active task to look at or search for particular features, so that real life outdoor landscape observation was simulated. Instead, subjects were instructed to observe the landscape photographs attentively. The display order of the photographs was randomized to avoid the emergence of order effects in the data. During the experiment, the participants were seated at a viewing distance of 60 to 80 cm. Before each test, a calibration was executed, using a 9-dot calibration procedure, allowing the system to match the pupil-centre/corneal reflection relationship to the specific x,y-coordinate of the fixed dot. After nine dots, an accurate calibration over the whole size of the screen is achieved (Goldberg and Wichansky, 2003). When subjects started deviating from these initial calibration conditions (see drift correction explained below) because of unintentional brusque movements or eye problems, the calibration procedure was repeated. In order to avoid fatigue effects, the participants were given the opportunity to take a break at any time during the experiment. This is necessary because it has been reported that observing images on a computer screen frequently causes eye fatigue (Blehm et al., 2005), which manifests itself by a decrease in the number of eye movements (Van Orden et al., 2000) and in their accuracy (McGregor and Stern, 1996). Each break was followed by a new calibration. Prior to each trial the subjects were instructed to fix a dot, shown in the centre of a blank screen to check for increasing measurement errors (drift correction) and to provide consistency on the initial conditions of the observation path of each photograph. For the analysis, the first fixation on each photograph was excluded as this was always located in the centre of the image and would thus bias the results. During the trials the system constantly recorded the fixations and eye movements (saccades) of the subject. A fixation can be defined as “the moment when the eyes are relatively stationary, taking in or encoding information” (Poole and Ball, 2005). Consequently, a fixation is characterized by a minimum duration, typically between 100 and 200 milliseconds (Jacob and Karn, 2003). Inhoff and Radach (1998) advise to set the lower threshold for defining a fixation on at least 100 milliseconds. Therefore, in our study a stationary eye position was considered as a fixation when lasting for at least 100 milliseconds. The fixation related metrics, which are relevant in studying the gaze pattern and thus relevant in our research, are the number of fixations and their duration (in milliseconds). Saccades are the eye movements that interconnect two fixations and orient the eyes to the next viewing position (Poole and Ball, 2005). In this study, we investigated the number of saccades and their amplitude (degrees) as these metrics offer insight into the main observation pattern. In addition, the entire scan path was analysed as well because it offers the possibility to find out how the observer has examined the image. According to Holmqvist et al. (2011), a scan path is the route of oculomotor events through space within a certain timespan, which assumes that the path has a beginning and an end and thus a length.

4.2.5 Data analysis

4.2.5.1 General analysis of ETM

For the statistical analysis of the Eye-tracking Metrics (ETM), the data recorded by the eye tracker were converted into well-structured Excel-files in 'BeGaze', a software program supplied with the equipment. These files were subsequently used to perform the statistical analysis in SPSS. The main research question is whether experts observe landscapes differently from lay people. Therefore, a comparison of means between both groups of observers was carried out for the following metrics, which are indicative for the main gaze pattern: number of fixations, fixation duration, number of saccades, saccade amplitude and scan path length. As most eye-tracking measures do not follow a normal distribution (Holmqvist et al., 2011), a non-parametric Mann-Whitney U-test was performed. This test, based on ranks, is used to detect whether observations in one group (experts) tend to be significantly larger or smaller than observations in another group (laymen). If the mean ranks are found to be significantly different, the observations in the two groups will significantly differ as well. Luminance maps illustrate the results of the analysis. These can be described as two-dimensional visualizations or 'maps', representing the spatial distribution of a scan path (Holmqvist et al., 2011). Luminance maps or attention maps are based on fixations and thus represent the areas that have been given attention by the observer. The scan paths, including fixations and saccades, are visualized on the original photographs as well.

4.2.5.2 Spatial distribution of Voronoi cells

Although the number of fixations and scan path length give a rough idea of the proportion of the image that has been inspected, these metrics do not offer certainty about the extent to which the photograph has been observed. Fixations can, for example, be clustered in one part of the image, which may lead to erroneous conclusions concerning the viewing extent, when based solely on fixation number and scan path length. As a result, an additional analysis was carried out to see to what extent experts' and laymen's fixations are spread out over the photographs. In literature this 'extent' is often referred to as 'fixation dispersion', 'distribution of gaze intensity' or 'spread of search' (Holmqvist et al., 2011). One manner to quantify this dispersion is the Voronoi cell mapping, introduced in eye-tracking analysis by Over et al. (2006). This method consists of attributing each fixation one cell, which is formed by a set of points in space whose distance to the given fixation is smaller than their distance to any other fixations (Figure 4.2). The Voronoi cells were automatically calculated and drawn in ArcGis 9.3 using the Spatial Analyst tool after loading the fixations as point layers. When fixations are dense, the Voronoi cells will be small. Dispersed fixations will be characterized by large Voronoi cells. For the analysis, the areas of the Voronoi cells corresponding to the fixations of the experts and lay people were automatically calculated in ArcGis and compared using a Mann-Whitney U- test.

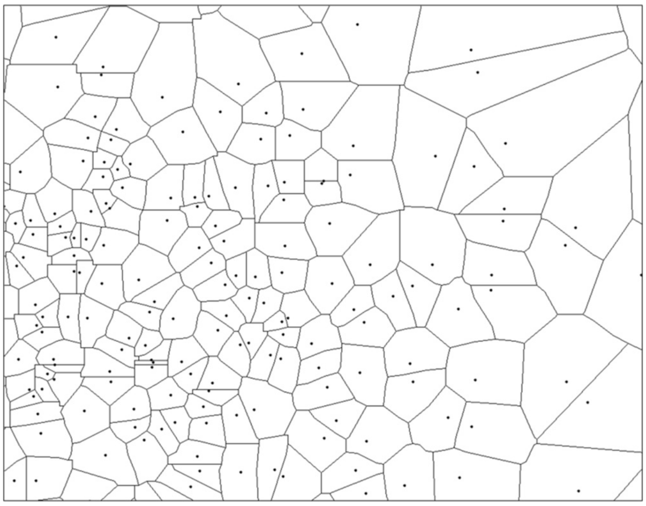

Figure 4.2 Fixations (dots) with their corresponding Voronoi cells.

4.2.5.3 Analysis of 'interest areas'

The general analysis of the ETM and the analysis of the spatial distribution of the Voronoi cells are used to understand the main observation pattern. However, no information is obtained about which objects in a landscape attracted the observer's attention. To answer this question we performed an exploratory screening of the luminance maps, created for each observer and each photograph. Based on the knowledge obtained from this qualitative analysis the most frequently observed elements could be identified. To perform a more quantitative analysis, polygons marking these objects were drawn on the photographs in BeGaze (Figure 4.3) (see section 4.3.3 for more details about the content of the interest areas). These 'interest areas' were subsequently used to calculate a number of eye-tracking metrics restricted to these areas and thus offering information about the viewing pattern concerning these specific areas. First, we calculated the number of visits per interest area for each observer. This is the number of times that a subject entered an interest area during the 10 seconds viewing time. The second interest area-metric is the time at which the first interest area of a photograph was entered. This provides information about how fast the objects in the interest area caught the observer's attention. Furthermore, per subject, the number of fixations in each interest area was counted in absolute terms and as a proportion (%) of the total amount of fixations one has made in the image. In addition, the fixation time in each interest area was obtained by totalizing the duration of the individual fixations made in the interest area. This metric was also expressed as the proportion (%) of the entire viewing time (10s) that was spent in the interest area. Finally, the duration of the first fixation in each interest area was included in the analysis as well. To detect any differences between the expert and laymen group, a statistical analysis (Mann-Whitney U-test) was performed on each metric.

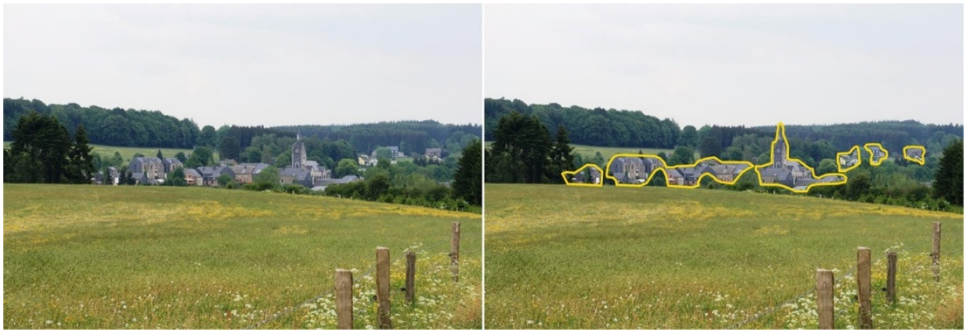

Figure 4.3 Illustration of the ‘interest areas’, which mark the buildings.

4.3 RESULTS

4.3.1 Fixations, saccades and scan path

For all ETM the Mann-Whitney U-tests indicate significant differences between landscape experts and laymen ($P < 0.05$) (Table 4.1).

Table 4.1 Results of the Mann–Whitney U-test (mean rank). Maximum values are indicated in dark grey, minimum values in light grey. Recorded mean values for each ETM are given for the experts and the non-experts. N gives the number of observations.

Eye-tracking Metric	N	Mean rank		P	Real mean values	
		Experts	Non-experts		Experts	Non-experts
Number of fixations	99,494	53,913	45,395	0.000	33	31
Fixation duration (ms)	99,494	48,993	50,536	0.000	264	273
Number of saccades	95,189	50,420	44,657	0.000	33	31
Saccade amplitude (°)	95,189	46,761	48,462	0.000	4.5	5.1
Scanpath length (px)	3,108	1,650	1,459	0.000	6,638	6,348

Experts seem to make significantly more fixations and saccades – both are inherently associated with each other – in the same amount of time compared to lay people ($P < 0.05$) (Table 4.1). During the 10 second trials experts were able to produce 33 fixations on average, compared to 31 fixations for the laymen. In addition, landscape experts' fixations are on average of shorter duration (264 ms) than those made by non-experts (273 ms) ($P < 0.05$) (Table 4.1). Furthermore, the Mann-Whitney U-test points out that the scan paths of the landscape experts are significantly longer (in fact, the on average shorter saccadic amplitude is completely drowned out by the significantly higher amount of saccades) than those made by the laymen group ($P < 0.05$) (Table 4.1 and Figure 4.4, section a and b). While an expert covers an average distance of 6,638 pixels when observing a landscape photograph for 10 seconds, a non-expert's mean distance is 6,348 pixels.

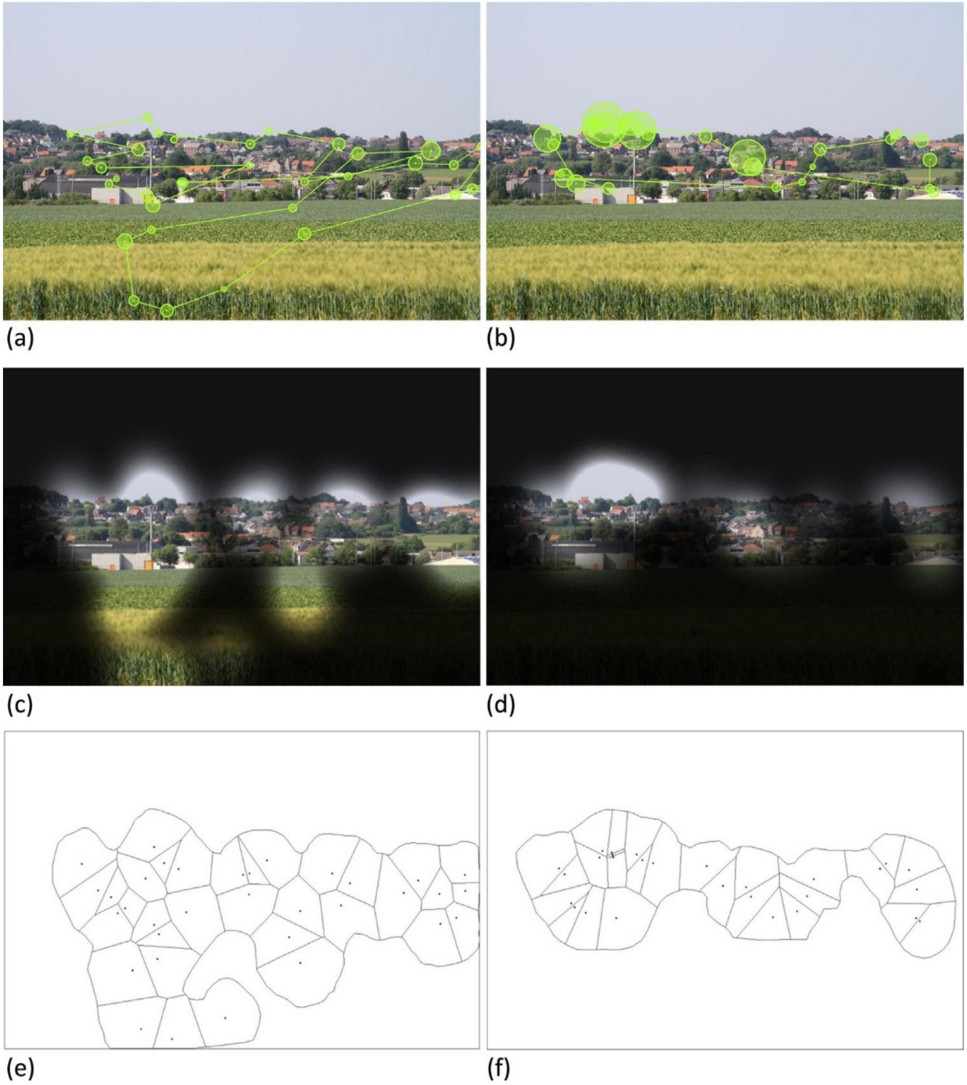

Figure 4.4 Scan paths of a landscape expert (a) and a non-expert (b), their corresponding luminance maps (c) and (d) and Voronoi cells constructed around the fixations and restricted to the observed area (e) and (f). In the scan path visualizations the size of the circles increases with fixation duration. On the luminance maps, the visible parts are the areas that have been viewed by the observer; the dark parts have not been given any attention. All representations are derived from fixations (detection from 100 ms) and are based on the entire 10 s trial.

4.3.2 Visual span

Figure 4.4 (section c and d) presents luminance maps for a landscape expert and a layman, derived from the scan path representation given in (a) and (b). Although the maps suggest that the area observed by the expert is larger and more extended than the non-expert's viewed area, quantitative analyses of luminance maps are difficult. Therefore, we performed an additional analysis, using Voronoi cells constructed around each fixation and restricted to the observed area in the luminance map (Figure 4.4, section e and f). The results of the Mann-Whitney U-test, in which the areas of the Voronoi cells corresponding to the fixations of the landscape experts and the laymen are compared, indicates a significant difference between the two groups ($P < 0.05$) (Table 4.2). In particular, the expert group is characterized by larger Voronoi cells, while for laymen they are significantly smaller.

Table 4.2 Results of the Mann–Whitney U-test for the Voronoi cell areas. Maximum values are indicated in dark grey, minimum values in light grey. N gives the number of observations.

	N	**Mean rank**		**P**
		Experts	**Non-experts**	
Voronoi cell surface	99,494	48,968	47,875	0.000

4.3.3 Focus: where do people actually look at?

The luminance maps show that the laymen's attention is mostly directed towards buildings and constructions like houses, farms, stables etc. and thus these features seem to be very important in guiding the viewing pattern. The same basic pattern, however, is found for the expert group. To detect any differences in attention between the two groups, a detailed quantitative analysis of the interest areas, drawn systematically around buildings and constructions, was performed. First, the results indicate that novices visit the interest areas as often as experts ($P > 0.05$): approximately 2 visits per interest area on average (Table 4.3). Since both groups seem to fixate buildings after approximately 2 seconds, no difference could be found in the time at which the first interest area is entered ($P > 0.05$). Furthermore, the statistical test does not reveal any significant differences in the absolute number of fixations made in interest areas by lay people and experts ($P > 0.05$). However, the proportion of the total amount of fixations occurring in the photograph seems to significantly differ between both groups ($P < 0.05$). On average, 17.98% of the fixations made by laymen were measured within an interest area, compared to 16.47% for the experts (Table 4.3), which means that a non-expert observer fixates relatively more on buildings. Furthermore, non-experts seem to spend significantly more time in the interest areas (1.6 seconds on average), while experts explore the buildings more quickly (1.4 seconds on average) ($P < 0.05$). In relation to the entire viewing time (10 seconds) lay people on average spend 15.53% of the time observing buildings. For the expert group this proportion decreases to 14.55% ($P < 0.05$). The duration of the first fixation made in each interest area also indicates how strongly buildings catch the attention. The statistical analysis shows that this first fixation duration is significantly different for experts and non-experts in that the first fixation made by non-experts seems to be longer, although the difference is subtle (Table 4.3) ($P < 0.05$).

Table 4.3 Results of the Mann–Whitney U-test for the interest area-metrics (mean rank). If significantly different, maximum values are indicated in dark grey, minimum values in light grey. Recorded mean values for each ETM are given for the experts and the non-experts. N gives the number of observations.

Eye-tracking Metric	N	Mean rank		P	Real mean values	
		Experts	Non-experts		Experts	Non-experts
Number of visits per interest area	4,647	2,310	2,338	0.459	2.44	2.48
Entry time of first interest area (s)	2,075	1,014	1,062	0.071	2.03	2.14
Number of fixations per interest area (all visits)	4,647	2,297	2,353	0.147	5.10	5.37
Percentage of fixations that fall into an interest area (all visits)	4,647	2,270	2,381	0.005	16.47	17.98
Fixation time per interest area (all visits) (s)	4,647	2,285	2,365	0.044	1.44	1.55
Percentage of fixation time per interest area (all visits)	4,647	2,285	2,365	0.044	14.55	15.53
Duration of first fixation in an interest area (ms)	11,421	5,650	5,775	0.043	283	286

4.4 DISCUSSION

4.4.1 Interpretation of the results

4.4.1.1 Fixations, saccades and scan path

Duchowski (2007) demonstrated that a larger *amount of fixations* in the same observation time increases the observer's memorization and recognition capacity. According to this theory, our findings could indicate that the memorizing capacities of landscape experts are larger than those of laymen as their higher fixation frequency enables experts to absorb and memorize more information in the same amount of time. In addition, the shorter *fixation durations* of experts indicate the ease with which the landscape photographs are processed and encoded. Former studies have pointed out that fixation duration reflects the processing-time spent on the object being fixated (Just and Carpenter, 1976), which in turn indicates the observer's difficulty obtaining information from or interpreting the given object (Fitts et al., 1950; Goldberg and Kotval, 1998; Duchowski, 2007). In general, it has been demonstrated that images or objects associated with long fixation durations are more difficult and effortful to interpret (Henderson et al., 1999; Holmqvist et al., 2011) or are not as meaningful to the observer as objects characterized by shorter fixations (Goldberg and Kotval, 1999). Consequently, the shorter fixations of the landscape experts, found in our study, mean that the degree of expertise in landscape related topics influences the processing-time spent on the objects constituting a landscape. Landscape experts seem to process information faster and interpret and identify the landscape objects more easily and more quickly. These results confirm the findings of Mann et al. (2007) who found that expertise causes differences in gaze behaviour, which are functional in terms of more efficient information pick-up. This saves time, which enables experienced landscape observers to produce more fixations in the same 10 seconds observation period. The landscape photograph can visually be explored more intensively, increasing the experts' capacity to identify and interpret individual objects and to recognize and memorize the image as a whole. These findings are consistent with the Information-processing Theory developed by Kaplan and Kaplan (1989a). According to this theory, there are two major categories of human needs, concerning information extraction from the environment: *understanding* and *exploration*. Like all other creatures, humans want to understand their environment and what takes place in it. Kaplan and Kaplan (1989a) state that this *understanding* depends, at least partially, on prior knowledge or experience. Our findings support this and indicate an easier and faster understanding of the environment by the experts because of their larger knowledge and training. Because of this 'advantage', landscape experts can spend more time on the *exploration* of the environment and obtain a more complete and detailed idea of the landscape. In turn, this more elaborate exploration expands the accumulation of experience and knowledge and increases the capacity to understand new, formerly confusing situations and facets, which again facilitates and accelerates the understanding of the environment and so on.

Saccade-related metrics can only be used to study the search pattern (Goldberg and Kotval, 1999), as no encoding takes place during eye movements (Rayner and Pollatsek, 1989; Mann et al., 2007). According to Goldberg and Kotval (1999) more *saccades* are indicative of a more extensive inspection. Our experiment shows that participants from the expert group made significantly more saccades than the lay people ($P < 0.05$), again suggesting that experts are able to visually explore the landscape images to a larger extent. In addition, the experts seem to make smaller saccades than the laymen ($P < 0.05$). As shorter saccades take less time to plan and to execute, this leaves more time for fixations and thus for information processing (Abrams et al., 1989).

These findings are consistent with results of similar expert/novice studies in other domains, which have demonstrated an increased number of fixations and saccades and shorter fixation durations associated with experts compared to laymen (Chapman and Underwood, 1998; Rayner, 1998; Vogt and Magnussen, 2007; Konstantopoulos, 2009). Most similar to our study is the research conducted by Vogt and Magnussen (2007), who performed an eye-tracking experiment in which artists and novices were asked to freely observe paintings, ranging from everyday scenes to pure abstraction. Like in our research, the experiment revealed that the artistically untrained participants used fewer and longer fixations when inspecting the images compared to the artists, who made significantly more, but shorter fixations. This strengthens the theory that expertise reduces the time required to process domain-specific information, offering experienced people the opportunity to visually explore the images to a larger extent by making more fixations and saccades in the same amount of time.

Besides fixations and saccades, the entire *scan path* provides valuable information about how and over which distance the observer has ‘travelled’ through the landscape photograph. The scan path length, which is generally calculated as the sum of all saccadic amplitudes in a scan path, may, in combination with luminance maps (see section 4.3.3), provide insights into the spatial extent of the observation (Holmqvist et al., 2011). The longer scan paths found for experts suggests that the extent to which the landscape is visually explored increases with expertise. However, making this conclusion should be considered with caution. For example, when an observer divides his/her attention among a few objects and constantly moves between these objects, he or she might have a long scan path while in reality only a small proportion of the image has been viewed. Further analyses based on Voronoi cells and luminance maps are necessary to control this issue (see section 4.3.2, 4.3.3 and 4.4.1.2).

4.4.1.2 Visual span

The larger Voronoi cells found in the expert group indicate a rather dispersed pattern of fixations. For the laymen, the Voronoi cells are smaller, showing that their fixations are more clustered (Figure 4.4). According to the interest area analysis this clustered fixation pattern can be explained by the lay people's greater focus on buildings compared to experts'. Buildings seem to catch and hold laymen's attention much more and longer, which as a result hampers their further visual exploration of the landscape. These findings support the assumption that experts seem to have a larger visual span than lay people when visually exploring landscape photographs. This result corresponds to the holistic model of image perception, which focuses on the extension of the visual span (Kundel et al., 2007). In short, this theory proposes changes in the perceptual processes due to expertise. In particular, Gauthier and Tarr (2002) demonstrated that when observing field-specific images, experts start with an initial global viewing of the image, followed by a more detailed decomposition of the picture into hierarchical, structural components. In other words, experts seem to process such images in a more holistic fashion than non-experts. Consequently, experts' visual span tends to be larger compared to laymen, whose observational span is more restricted (Gauthier and Tarr, 2002). However, the question remains if because of this holistic viewing pattern, experts also spend more time on deducing relationships between the different objects rather than of viewing individual elements like non-experts probably do. Although this hypothesis has been confirmed for artistically trained and untrained viewers, who were asked to observe a number of paintings (Nodine et al., 1993; Vogt and Magnussen, 2007), further research is necessary to determine if similar conclusions are valid for landscape experts and laymen.

4.4.2 Implications for participatory landscape planning and management based on visual landscape assessments

Our findings may be important for participatory landscape planning, in which different focus groups are often consulted to evaluate potential landscape changes based on landscape photographs. Such visual landscape assessment studies aim at evaluating the visible features of a landscape for purposes of management, planning or design (Palmer and Hoffman, 2001). More and more, these studies involve public judgments besides expert appraisals (Selman, 2000; Palmer and Hoffman, 2001; Selman, 2006). Opinions are often probed using visualisations, as landscape management is inextricably linked to perception (Berlan-Darqué, 2008). Especially in the field of landscape management and planning, ‘understanding’ is very often equal to ‘seeing’ (Kaplan and Kaplan, 1989b). Moreover, people tend to make judgments based on what they see, more than on what they know. As a result, visualisations, which have been demonstrated to provide information in an understandable way, are a widely used medium when assessing landscapes (Bell, 2001). However, what people see may vary according to a number of factors. Chua et al. (2005), for example, states that differences in eye movements, memory for scenes and perceptual judgments could be caused by differences in experience and expertise. In particular, it is assumed that experts look differently at something that is presented in their “expert language” – in this case landscapes or landscape photographs – than lay persons (Lange, 2005). The reason for this phenomenon is that experts master key principles around which knowledge is hierarchically structured (Van Heuvelen, 1991). In landscape related topics, this difference in knowledge is reflected by a difference in perception: landscape professionals tend to dissect the landscape into all its constituent elements, while lay people don't (Scott, 2002). People with different backgrounds and different levels of expertise might thus look for different things in a landscape (Bell, 2001) and might consequently not see the same landscape (Meinig, 1979; Bell, 2001; Stewart et al., 2004). As a result, judgments and opinions formed based on what has been perceived could differ as well (Bell, 2001; Chua et al., 2005). This is an important issue for visual landscape assessment studies in which landscape professionals and lay people are consulted. So far, many studies have demonstrated significant assessment differences between both groups (Godschalk and Paterson, 1999; Bell, 2001). However, almost none has reported on how the lay persons and the experts actually observed the landscape images. Neither has been checked if both groups looked at the same features in the landscape and thus formulated their assessment based on the same elements of the landscape. Our study points out that landscape experts and lay persons do perceive landscape photographs differently and as a consequence probably do not see the same landscape: while experts explore the landscape as a whole with detailed inspections of its constituting elements, lay people have a much more restricted viewing pattern only focussing on a few elements, mainly buildings. Although, we did not investigate people's opinion about the landscapes, it could be that this different viewing behaviour may lead to diverging assessments. In turn, this may cause discord and discussions which could delay or even hamper landscape development or planning. The first step to avoid this consists of better understanding assessments of different (groups of) respondents by verifying on which features in a landscape an assessment was based. This could be achieved using eye-tracking, which offers the possibility to check where people consciously and unconsciously look at in a scene when making an evaluation. In addition, eye-tracking results could also be used to show landscape professionals that they literally have a different view on landscapes than lay people and that this dissimilar observation pattern should be taken into account when trying to unify different assessments. This is important because nowadays most of the time experts are not aware of these different views and perceptions of the landscape (Strumse, 1996).

4.4.3 Recommendations for further research

While this study provides essential information about how expertise influences the observation of landscape photographs, more research should be performed to examine this topic in greater detail. In particular, two main issues should be investigated to check their impact on the results. First, the results presented in this study are valid when a limited viewing time of 10 seconds is imposed. In eye-tracking terms this is a very long exposure time and several authors have demonstrated that the gist of a scene is accurately assimilated and consolidated into memory in the a few hundred milliseconds (less than 200 ms according to Potter et al. (2002), 500 ms according to Biederman et al. (1983) and Thorpe et al. (1996)). As such, a lot of the semantic content is perceived within a single glance of a scene (Biederman, 1972; Boyce et al., 1989; Thorpe et al., 1996; VanRullen and Koch, 2003; Grill-Spector and Kanwisher, 2005). However, it is not sure that an opinion about an image is completely formed in this first half of a second. Potentially, it can change when viewing the image for a longer time when, for instance, smaller details of the image are discovered which were initially omitted. This would imply that when viewing times increase the visual span as reflected in the luminance maps would expand. Furthermore, the question raises how the luminance maps of the experts and laymen would evolve and if the difference between both would increase or decrease. We believe that these are important issues to further investigate as in landscape assessment situations time limits are very unlikely.

Second, the differences in viewing patterns between experts and laymen may to some degree be caused by the free-viewing condition. For example, it is possible that as a result of their knowledge, the experts might have performed a landscape diagnostic and as such unconsciously have created their own ‘task’. This phenomenon is less likely to occur for lay people as they are missing this knowledge. However, the creation of an own task can never be completely ruled out. While in fact this is an expression of the presence or absence of expertise and knowledge, it does not affect the validity of our results. Instead, it could offer an explanation as to why differences in perception occur. A well-known technique used to probe people’s mental processes and thoughts is to apply the thinking aloud-method, in which participants are asked to tell out loud everything which crosses their mind while observing images (Nielsen, 1993; Van Someren et al., 1994). In future studies this should be used in order to identify the underlying processes which lead to different observation patterns.

4.5 CONCLUSIONS

In this study we investigated if expertise in landscape related matters influences the way people observe landscape photographs as this could be valuable information for understanding why landscape experts and laymen often seem to have divergent judgments when visually evaluating landscapes. Our eye-tracking experiment reveals a significant difference in viewing pattern between landscape experts and lay people. Acquired educational or professional expertise with respect to landscapes seems to enhance efficient information extraction in terms of an improved interpretation, identification and understanding of landscape objects. This reduces the time required to process the information registered by the eyes, offering an expert the opportunity to visually explore the photograph to a larger extent. As a result, the main viewing pattern of landscape experts consists of exploring the landscape as a whole, with short focuses on many different elements. This is reflected by a number of eye-tracking metrics, like a higher number of fixations and saccades, a longer scan path, a more dispersed fixation pattern and thus a larger visual span. In summary, landscape experts seem to observe landscape photographs in a holistic fashion, consisting of a global scanning of the image alternated with more detailed inspections of particular components. In contrast, non-experts spend considerably more time and attention to specific objects, in particular to buildings, restricting their visual exploration of the landscape. This is reflected in a smaller amount of fixations and saccades, a shorter scan path, a more clustered fixation pattern and a smaller visual span. Unlike landscape experts, laymen’s focus is mainly on singular elements in the landscape and less on the landscape as a whole. This behaviour can be a consequence of the lack of expertise or knowledge regarding landscapes, which makes longer fixations on individual objects necessary to resolve uncertainty or confusion about them and to understand their meaning. Consequently, information processing is slower, leaving less time to explore the image in the fixed test time.

These results are of particular interest for participatory landscape planning and management for which experts as well as the public are often consulted to visually assess new landscape developments. As differences in expertise influences how a landscape is observed, an expert and a lay man will not focus on the same features in a landscape and thus might not see the same content. As a result, their assessments will be based on different aspects of a landscape and might thus be very divergent. This should be taken into account when consulting different groups of respondents with diverse backgrounds for carrying out visual landscape assessments. In particular, eye-tracking could be used for checking which features of the landscape have been perceived before making the assessment.

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PART III

APPLICATION IN LANDSCAPE PLANNING AND DESIGN

CHAPTER 5: COMPARING SALIENCY MAPS AND EYE-TRACKING FOCUS MAPS: THE POTENTIAL USE IN VISUAL IMPACT ASSESSMENT BASED ON LANDSCAPE PHOTOGRAPHS

Modified from:

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ABSTRACT In this study, we analyse how well saliency maps, which are theoretical predictions of the human viewing pattern, are correlated with human focus maps, obtained by tracking 42 observer's eyes while free-viewing landscape photographs ranging from rural to urban environments. The Pearson's correlation coefficient was calculated on the predicted and measured pixels' greyscale values. A relatively high correlation was obtained, indicating that the saliency maps can be used as reliable predictions of the human observation pattern and thus can predict which elements in a landscape will catch the attention. These findings are useful in visual impact assessment, a step in the planning process which is often not well elaborated or even skipped. Saliency maps could, for instance, be used to compare the conspicuity of different designs of a construction when simulated in photographs of the original landscape. As the visual impact of an object is reduced when its visual perception decreases, the least salient design will also have the lowest visual impact and will correspond to the best integration into the existing landscape. This method is easy and produces an objective measure of the degree of visual impact. However, as slight differences in correlation depending on the degree of urbanisation of the landscape were found, this methodology will not be equally reliable in all types of landscapes. Predictions of the viewing pattern in rural landscapes with a limited amount of

buildings have been demonstrated to be most reliable. In more urbanised landscapes this reliability slightly decreases but nevertheless remains significant.

KEYWORDS: Correlation analysis, viewing pattern, visual conspicuity, urbanisation, visual landscape integration, landscape design

5.1 INTRODUCTION

When observing visual scenes, the resulting eye movements are not simply a set of random fixations. Instead, the fixations will exhibit a specific pattern (Humphrey and Underwood, 2009). The selection of locations to be fixated takes place according to a specific strategy, embedded in the human nervous system (Harel et al., 2012). As it would be computationally too demanding to process the massive amount of incoming sensory information all the time, the nervous system constantly decides which parts of the available information will be selected for further, more detailed processing and which parts will be skipped. In addition, the selected parts are ranked by priority. The most important parts will be processed first, less important ones will follow later. This process is called 'selective attention'. As attention to an object is necessary for it to be perceived consciously (Harel et al., 2012), only a small part of the incoming information will thus reach visual awareness (Desimone and Duncan, 1995; Crick and Koch, 1998). This means that when observing images, attention will be allocated only to a limited part of the image. Two main aspects influence how the attention is distributed: the content of the scene (bottom-up, low-level process) and the cognitive characteristics of the observer (top-down, high-level process) (Rajashekar et al., 2008). While the fast bottom-up mechanism is always operating – although stronger in free-viewing situations – the top-down mechanism predominantly comes into effect when performing tasks (; Yarbus, 1967; Land and Hayhoe, 2001; Parkhurst et al., 2002; Navalpakkam and Itti, 2005; Rajashekar et al., 2008; Borji et al., 2013).

In the particular case of landscapes, bottom-up processes will mainly drive the observation as people usually observe scenes freely and without a task in mind (Dupont et al., 2014). Consequently, the distribution of fixations will be primarily guided by the content of the visual stimulus (e.g. landscape photographs). Of particular interest in this situation are saliency maps, which can be described as computationally generated focus maps, which encode for conspicuity or salience at each location in an image in a purely bottom-up fashion (Itti et al., 1998; Itti and Koch, 2000; Itti, 2005). Salience or saliency is defined as the distinct perceptual quality by which an item in the world stands out from its neighbours and therefore immediately catches the attention (Itti, 2007). A feature's salience is calculated based on its colour, orientation and intensity information compared to its surround (Koch and Ullman, 1985; Itti et al., 1998; Itti and Koch, 2000, 2001; Peters et al., 2005). Objects which are in sharp contrast with or incongruent to their surroundings will thus 'pop out' in the saliency map and can be identified. This technique might be useful in landscape planning, -architecture and -design, and in particular in visual impact assessments of new projects – e.g. buildings, roads, bridges etc. – for estimating how well different scenarios are visually integrated in the surrounding landscape. As the visual impact of a new construction or modification is associated with its contrast with the background landscape, saliency maps obtained for different visualisations of the project can be used to objectively quantify these contrasts. As highly contrasting elements have been shown to capture people's attention (Itti, 2007), this measure can be used to assess the visual impact of a construction. However, before this method can be used and applied – which will not be done in this paper – empirical evidence of a substantial correlation between saliency maps of landscape scenes and focus maps, obtained from real observers who viewed the scenes, is required to demonstrate the validity of using saliency maps as predictions of the human viewing pattern in landscape photographs (which is the purpose of this study). This validity is very likely as eye movements have been demonstrated to be attracted to salient regions (Koch and Ullman, 1985; Itti and Koch, 2000; Itti, 2005). In fact, the similitude between saliency maps and human observation patterns has been confirmed in several studies (Peters et al., 2005; Humphrey and Underwood, 2009; Harel et al., 2012). However, for landscape photographs in particular this similarity has not yet been investigated thoroughly, while this analysis is an important first step in investigating the potential of saliency maps for objectively predicting a viewer's attention distribution in a landscape image and thus for identifying where and when objects are more likely to have a strong visual impact.

In this paper, we perform this analysis by investigating how well saliency maps approximate human focus maps when free-viewing landscape photographs by examining the correlation between both. As such, we check whether saliency maps can be used as reliable predictions of the viewing pattern in landscape visualisations and thus if they are usable for visual impact assessments. In addition, we examine if the result of this analysis is equal in different types of landscapes, ranging from rural settings to urban environments. This is of particular interest as the degree of urbanisation of a landscape has been demonstrated to have an effect on the observation pattern (Dupont et al., 2015a and 2015b).

5.2 METHODS

5.2.1 Theoretical background of saliency

Saliency is solely based on the bottom-up attentional process (Itti et al., 1998), which is a fast and stimulus-driven mechanism (Parkhurst et al., 2002). In particular, for each pixel in the image the salience is calculated based on its colour, orientation and intensity information compared to its surround (Koch and Ullman, 1985; Itti et al., 1998; Itti and Koch, 2000, 2001; Peters et al., 2005). As such, each pixel of the original image is ascribed a scalar value which indicates its salience (Itti, 2005; Peters et al., 2005). As the human eye tends to be attracted by salient objects in the visual environment (Itti, 2005), attention will first be attracted by the most salient region in the stimulus, i.e. the brightest area with the highest colour contrast and orientation change, then by the second most salient region etc. (Humphrey and Underwood, 2009). This guidance of the eye is completely driven by bottom-up mechanisms (Itti et al., 1998; Malcolm and Henderson, 2010). Shifting attention away from these regions will thus require voluntary top-down 'effort' (Itti and Koch, 2000, 2001) in order to surpass the bottom-up mechanisms of attention stemming from the characteristics of the visual stimulus (Treisman and Gelade, 1980; Nothdurft, 2005). This slower top-down process, determined by cognitive phenomena driven by the observer's expectations or intentions (Parkhurst et al., 2002), typically comes into play when performing tasks (Yarbus, 1967; Land and Hayhoe, 2001; Navalpakkam and Itti, 2005; Rajashekar et al., 2008; Borji et al., 2013), although the bottom-up guidance mechanism can never be completely ruled out (Parkhurst et al., 2002). As in free-viewing no tasks are involved, saliency maps have been especially successful in predicting fixations when free-viewing images (Parkhurst et al., 2002; Peters et al., 2005; Foulsham and Underwood, 2008). For a mixture of images, a high correlation between saliency and human fixations has been confirmed in a number of recent studies (e.g. Parkhurst et al., 2002; Peters et al., 2005; Humphrey and Underwood, 2009; Borji et al., 2013).

5.2.2 Subjects

Forty-two subjects voluntarily participated in the eye-tracking experiment. They were given brief practical information about the test but no details were revealed with respect to the purpose of the study in order to avoid influencing their viewing pattern in advance. A mix of females (24) and males (18) aged between 22 and 65 was obtained. When applicable, the participants were asked to wear contact lenses instead of glasses if possible because otherwise the eye-tracker could erroneously lock onto the dark parts of the glasses instead of onto the pupil. For the same reason, mascara was prohibited. Before starting the test, the participants were asked about any aberrations of their eyes. The 42 selected subjects all had normal or corrected-to-normal vision.

5.2.3 Stimuli

As we are investigating how people observe landscapes, we use terrestrial landscape photographs in the eye-tracking test. This is allowed since numerous authors have confirmed the validity of using photographs as surrogates for real landscapes (e.g. Zube et al., 1987; Palmer and Hoffman, 2001). In addition, performing the test in situ has many drawbacks of which the time consumption, the high cost and the difficulty in controlling the settings of the experiment are the most important.

The photographs were taken following a strict routine to allow an unbiased comparison between them. First, all photographs were taken with the same camera and have a resolution of 3888 x 2592 pixels. Second, the focal length of the objective was kept constant at 50 mm in order to obtain equal visual angles (± 31° x 21°). Third, a tripod was used to assure a constant shot height of 1.70m. Fourth, the horizon was always placed at the same height in the photograph (2/3 of land, 1/3 of sky). Finally, all the photographs were taken in the same season to assure consistency about the condition of the foliage. The represented landscapes, 74 in total and ranging from rural to urban environments, are situated in Belgium and the north of France.

5.2.4 Eye-tracking apparatus

The eye-tracking experiment was performed in the Eye-tracking lab of the Department of Geography of the University of Ghent. A RED250- eye-tracking device, developed by SMI (Senso Motoric Instruments), was used to record the gaze pattern of the participants while observing the landscape images. This is possible as the eye-tracking technique consists of sending infrared light into the pupil of the observer (Duchowski, 2007). The reflected signal then provides information about the exact location of the point-of-regard on the screen (when calibrated) (Jacob and Karn, 2003; Poole and Ball, 2005). As such, all the stationary gaze positions (fixations) and interconnecting eye movements (saccades) are recorded (Poole and Ball, 2005). In this study, the threshold for determining when a position is stationary, and thus for defining a fixation, was set at 100 milliseconds in accordance with Inhoff and Radach (1998). Afterwards, this data can be ‘replayed’ and visualised on the observed image to gain insight into which areas in the image received attention. During the experiment, the participants were seated 60 to 80 cm (depending on the optimal calibration position) in front of a 22-inch colour monitor on which the photographs were displayed. Both eyes were tracked at a measurement rate of 120Hz, which is equal to 120 measurements per second.

5.2.5 Procedure

The eye-tracking experiment consisted of free-viewing 74 landscape photographs, shown for 10 seconds each. The display order of the photographs was randomized to avoid the occurrence of effects originating from a fixed order. The participants were given no specific tasks but attentively observing the images. Free-viewing was chosen for two major reasons. First, we wanted to reproduce real life outdoor landscape observation conditions, which generally does not imply any tasks (Dupont et al., 2014). In addition, free-viewing most closely approximates natural viewing conditions (Parkhurst et al., 2002), which is what we aimed at. Second, the purpose of the study – comparing the viewing pattern of the participants with the prediction of the saliency map – requires free-viewing conditions. As saliency is based solely on bottom-up mechanisms of attention, the presence of top-down influences on the viewing pattern of the participants would make a proper comparison impossible. Although complete suppression of top-down influence cannot be achieved (Mannan et al., 2009; Borji et al., 2013), free-viewing reduces the task dependent top-down effects on eye movements to a minimum (Parkhurst et al., 2002).

Before starting the test, all the participants were given the same instruction text. After reading the instructions, a 9-dot calibration was performed to assure accurate measurements over the entire screen. After each image, the participants were asked to fixate a dot in the middle of the screen so that deviations from the initial calibration could be detected. When necessary a recalibration was performed. The drift correction dot also provided consistency on the starting point of the observation of each photograph.

5.2.6 Classification of photographs based on the degree of urbanisation

The ranking of the photographs, done by the participants, was obtained by using the Q-sort method like presented by Pitt and Zube (1979). This task was performed after the eye-tracking test in order to avoid biasing the observation pattern, which could occur when seeing the photographs for the second time. The participants were asked to sort the photographs depending on the amount of built area present in the landscape in order to obtain 5 classes of urbanisation. Therefore, the photographs were all presented on a desk. First, the participants had to pick out the 12 landscape photographs that were least characterised by built content. Second, the 12 photographs in which contained a maximum of built area were selected. This two-step procedure was repeated for the remaining 50 photographs but this time 16 photographs had to be selected each time. Finally, the last 18 photographs formed the last urbanisation class. This procedure provided 5 classes of urbanisation labelled as follows: Rural, Semi-rural, Mixed, Semi-urban and Urban landscapes (Figure 5.1). This classification was validated by objectively calculating the percentage of urbanised area in each photograph and comparing this to the score obtained from the Q-sorting. A correlation analysis confirmed a strong correlation between both variables (correlation coefficient of 0.959, $P < 0.001$) (see Dupont et al. (2015b) for further details). In consequence, the classification can be used for statistical comparisons.

Once the sorting task was completed by all the participants, scores were assigned to each urbanisation class as depicted in Table 5.1.

Figure 5.1. Examples of the different urbanisation classes: (a) Rural, (b) Semi-rural, (c) Mixed, (d) Semi-urban, and (e) Urban landscapes (from Dupont et al., 2015b).

Subsequently, the average score across participants was calculated for each photograph. Based on this value, the photographs were assigned to one of the five classes of urbanisation. This final classification, however, could not be effectuated unequivocally as a number of photographs seemed to be in the middle between two classes (scores close to 1.5, 2.5 etc.). Assigning these images to one of the two classes would be very arbitrary, which could bias the results. Consequently, all the photographs of which the score indicated doubt, were removed from the analysis, leaving 10 photographs in each urbanisation class, 50 in total.

Table 5.1. Theoretical scheme for the classification according to the degree of urbanisation.

Urbanisation class	Rural	Semi-rural	Mixed	Semi-urban	Urban
Number of photographs	12	16	18	16	12
Score	0	1	2	3	4

5.2.7 Data analysis

5.2.7.1 Creating the saliency maps and focus maps

For each photograph, a saliency map (Figure 5.2) was created in Matlab using the GBVS (Graph-based Visual Saliency) algorithm as developed by Harel et al. (2006) and provided on http://www.klab.caltech.edu/~harel/share/gbvs.php (Harel, 2012). Out of other possible saliency algorithms the GBVS algorithm was chosen because it has been demonstrated to yield the highest correlation coefficients over datasets consisting of landscape scenes amongst other images (Borji et al., 2013b). As a result, it is assumed that for this kind of images, human predictions are more reliably predicted by the GBVS than by other algorithms (Harel et al., 2006).

The focus maps, based on the eye movements registered during the experiment, were created in BeGaze, the software package provided with the SMI eye-tracker (Figure 5.2). This was achieved for each participant for each photograph (3,108 focus maps in total). Generally, the focus map is projected onto the original image to highlight the observed areas and obscure the unwatched areas. However, the presence of colours stemming from the original photograph in the focus map would not allow a proper comparison with the greyscale saliency map. Therefore, the original image was replaced by a white image. As a result, greyscale focus maps were obtained (3,108 in total) with colour values ranging from 0 (black) to 255 (white) consistent with the saliency maps.

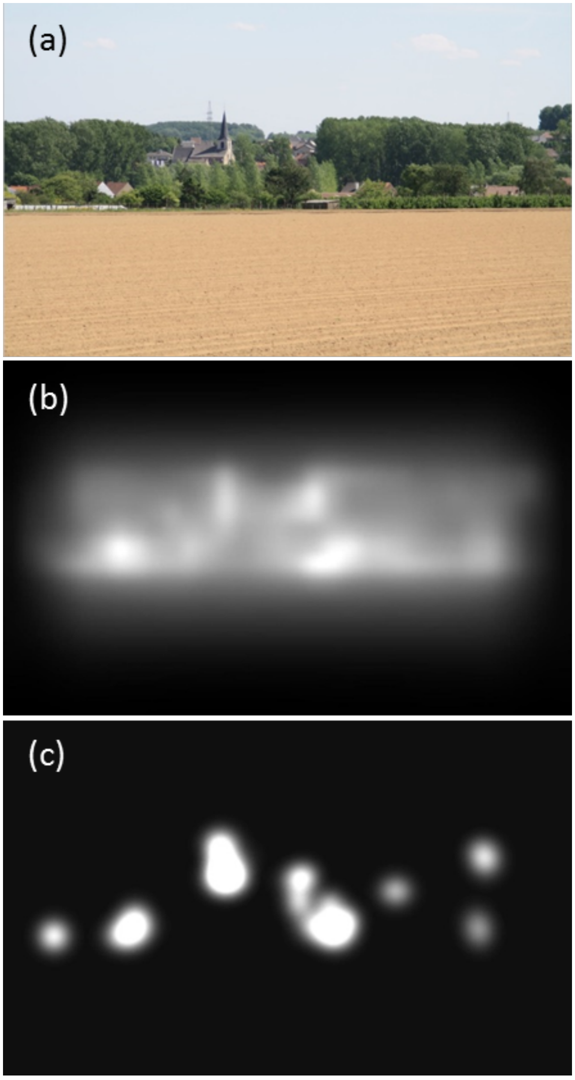

Figure 5.2 (a) Original landscape photograph, (b) Saliency map of the photograph, (c) Example of a focus map based on the fixations made when observing this photograph.

5.2.7.2 *Comparison of focus maps with saliency maps*

In order to be able to compare the focus maps of the participants with the theoretical saliency maps (for each photograph, 42 focus maps (one for each participant) was compared with the corresponding saliency map for that photograph (74 in total)) a number of operations were needed (Figure 5.3). First, the focus and saliency maps (.jpg-images) were transformed into text-files (.txt) containing the values, which define the greyscale colour of each pixel. This was executed in ArcGis 10.1 using the conversion command *Raster to ASCII*. The result is a 1050x1680 matrix of values for each focus and saliency map (their resolution differs from the resolution of the original photographs as the eye-tracking software automatically downscales all original and processed images to 1050 x 1680 images). Second, these matrices were rearranged into one column per image, working from left to right and starting with the first row of the matrix, then the second etc. During this operation, the average value per two adjacent pixels was calculated and stored in the final column. As a result, the column contained 882,000 records in total instead of the 1,764,000 (1050*1680) records when all pixels would have been included. This number, however, was too elevated to be handled properly and quickly by the SPSS software (see next section). In addition, this 'downgrading' is allowed since the accuracy of the eye-tracker is 0.5°, which corresponds to 54 pixels at a viewing distance of 60 cm. Consequently, averaging 2 pixels will not significantly affect the analysis. This is confirmed by an analysis of the distribution of the differences in value across the averaged pairs: for the saliency maps, 86.6% of the pairs had the same value and 99.6% had a difference of 1, while 83.1% of the pairs in the focus maps were equal and 99.7% had a difference of maximum 5. These differences are negligible considering that the values vary between 0 and 255. Finally, the datasets – one per photograph, 74 in total – necessary for the comparison were obtained by aggregating the columns of the focus map of each participant (42 columns) with the column of the corresponding saliency map (1 single column). This resulted in one table per photograph consisting of 43 columns (42 columns of focus values and 1 column of saliency values), each containing 882,000 records. As such each of the 3,108 focus maps could be compared to the corresponding saliency map.

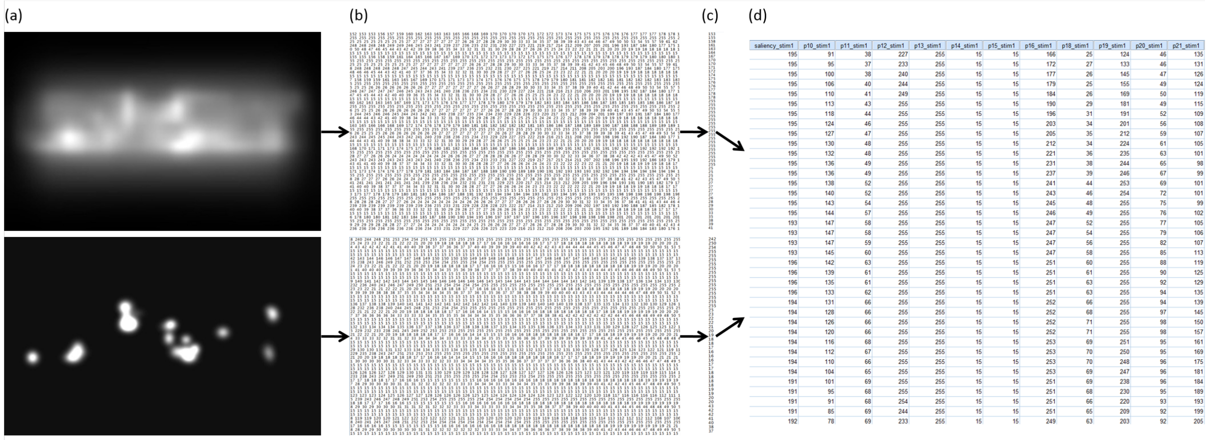

Figure 5.3 Different steps in the transformation process: (a) initial images (2100 focus maps and 50 saliency maps), (b) transformation into text-files with values defining the greyscale colour of each pixel (1050 × 1680 matrices), (c) rearrangement of each matrix into one column per image (average value per two horizontally adjacent pixels,882,000 records per image), and (d) aggregation of the columns of the focus maps and the column of the corresponding saliency map (1 final dataset per photograph, consisting of 43 columns).

As the aim of the study is to analyse how close the viewing pattern of the participants is to the predicted saliency map, a comparison between both was performed based on the above-mentioned datasets. In particular, the correlation between each focus map (3,108 in total) and its corresponding saliency map was determined by calculating the Pearson correlation coefficient, which is a statistic often used to compare human focus maps and saliency images (e.g. Ouerhani et al., 2003; Rajashekar et al., 2004; Rajashekar et al., 2008; Borji et al., 2013b; Haass et al., 2015). The overall correlation coefficient (based on 74 photographs) was calculated as well as the correlation coefficient of each of the five urbanisation classes (based on the 50 unequivocally classified photographs). Since raw correlation coefficients are not additive and thus average values cannot be computed, a Fisher's Z transformation was performed onto the correlation coefficients (Sheskin, 2003). To check if significant differences in correlation occur between these classes a Kruskal-Wallis test in combination with a Dunn's test was performed in SPSS. In addition, the correlation between the Fisher's Z values (correlation between focus maps and saliency maps) and the percentage of urbanised area (square root to obtain a normal distribution) was computed for the 74 images.

5.3 RESULTS

The average Pearson correlation coefficient (after performing a Fisher transformation) over all photographs and all participants is 0.410 and was found to be significant ($P < 0.01$), which indicates a medium positive correlation between the human focus maps and the theoretical saliency maps. The correlation coefficients calculated for the five urbanisation classes separately are all significant as well ($P < 0.01$). Furthermore, significant differences in correlation between the five classes were found ($P < 0.01$) (see Figure 5.4 and Table 5.2). In particular, the highest correlation coefficients are found for the semi-rural landscape photographs (0.530, $P < 0.01$), it subsequently decreases for mixed landscapes (0.476, $P < 0.01$) and semi-urban landscapes (0.391, $P < 0.01$) to reach a minimum for the urban landscape photographs (0.327, $P < 0.01$). Thus, when disregarding the rural landscapes, there seems to be a trend of decreasing correlation when the degree of urbanisation in the landscapes increases. This is also reflected in the correlation between the Fisher's Z values and the square root of the percentage of urbanised area, which was found to be -0.470 ($P < 0.01$) for all images and -0.557 ($P < 0.01$) when the rural category images are excluded (as this category does not follow the linear relationship). This means that when the proportion of buildings in the photograph decreases, the viewing pattern comes more close to the prediction of the saliency map. In landscapes in which more built area is present, the human viewing pattern seems to much less follow the saliency map. Rural landscapes are an exception to these findings as the correlation (0.438, $P < 0.01$) in this type of landscapes is lower than would be expected based on their lowest degree of urbanisation. Based on the trend, rural landscapes would have been expected to generate the highest correlation coefficients.

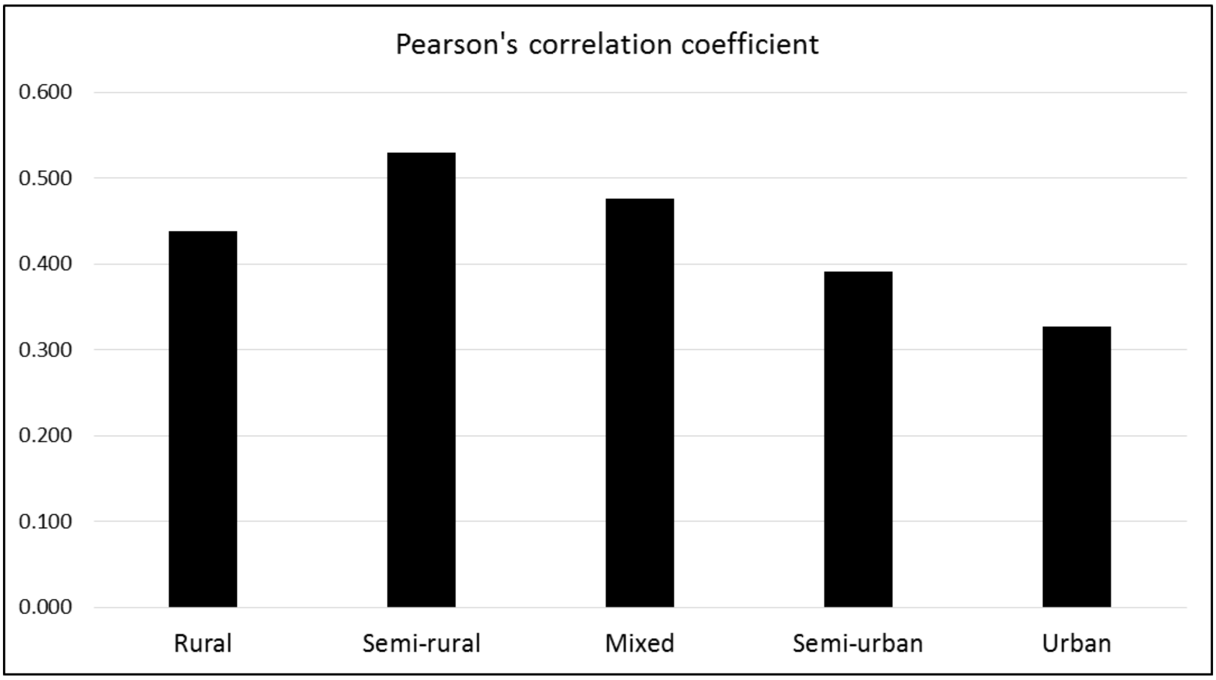

Figure 5.4 Average Pearson correlation coefficient (after Fisher transformation) per urbanisation class.

Table 5.2 Results of the Kruskal–Wallis (ranks) and Dunn's test per photograph type. N gives the number of observations. (A Fisher transformation was applied to the Pearson's correlation coefficients).

	N	Mean rank per landscape type					P
		Rural	Semi-rural	Mixed	Semi-urban	Urban	
Pearson's correlation coefficient	2,100	1,082	1,440	1,249	877	604	0.000
	N	Real mean values per landscape type					
		Rural	Semi-rural	Mixed	Semi-urban	Urban	
Pearson's correlation coefficient	2,100	0.438	0.530	0.476	0.391	0.327	

5.4 DISCUSSION

5.4.1 Validation of the methodology

Our analysis generates correlation coefficients, which are in the same order of magnitude as the ones reported by Borji et al. (2013) who provide an overview of the prediction performance of different saliency algorithms. While we found a mean correlation of 0.410, Borji et al. (2013) mention correlation coefficients varying between 0.280 and 0.450 for the GBVS. However, the images in this study did not solely consist of landscape photographs but of a mixture of landscape photographs, images of indoor environments and portrait images. Furthermore, the correlation coefficient as calculated by Borji et al. (2013) differs from the approach exhibited in this study. Borji et al. (2013) determine the correlation between the saccade frequency at each location and the corresponding saliency, while our correlation is calculated between the pixel information, consisting of the greyscale value, in both focus and saliency maps. As focus maps are calculated based on fixations, the greyscale value is related to the fixation density. Both correlation coefficients can thus be considered as similar, since fixations and saccades are inherently correlated. While these constraints impede a perfectly proper comparison, it nevertheless offers an indication of the validity of the method used in this paper.

5.4.2 Interpretation of the results

The relatively high, significant correlation coefficients - definitely in comparison to correlation coefficients found for other datasets or other saliency algorithms (see Borji et al., 2013b for an overview) - found between the human focus maps and the saliency maps indicate that the latter can be considered as fairly reliable predictions of the human viewing pattern in landscape photographs. The fact that the correlation decreases when the degree of urbanisation in the landscape increases implies that the viewing pattern appears to be less predictable when the amount of build content increases (e.g. Semi-urban and Urban landscapes). In less urbanised landscapes characterised by a restricted number of buildings (e.g. Semi-rural and Mixed landscapes) this predictability is higher. As the difference between the five landscape categories tested in this study is based solely on the criterion “amount of buildings”, it can be deduced that the predictability of the human viewing pattern seems to be influenced by the degree of urbanisation of a landscape. When buildings are sparse, they have been demonstrated to act as eye-catchers when observing landscape photographs (Dupont et al., 2015a). This can explain the higher correlations in semi-rural and mixed landscapes because, as buildings visually often stand out of their surroundings (by colour, texture etc.), there is a high probability that they will be identified as highly salient by the saliency algorithm. When the proportion of buildings in a scene becomes too large, this effect fades out. Human observers then seem to ‘lose track’ and start looking around without clear targets to fixate upon (Dupont et al., 2015b) (Figure 5.5). In fact, this pattern emerges because photographs of more urbanised environments contain much more details and thus have a higher information content resulting in a less structured, scattered viewing pattern as people try to assimilate as much information as possible (Dupont et al., 2015b) (Figure 5.5). This viewing pattern could explain the lower correlations found in semi-urban and urban landscapes.

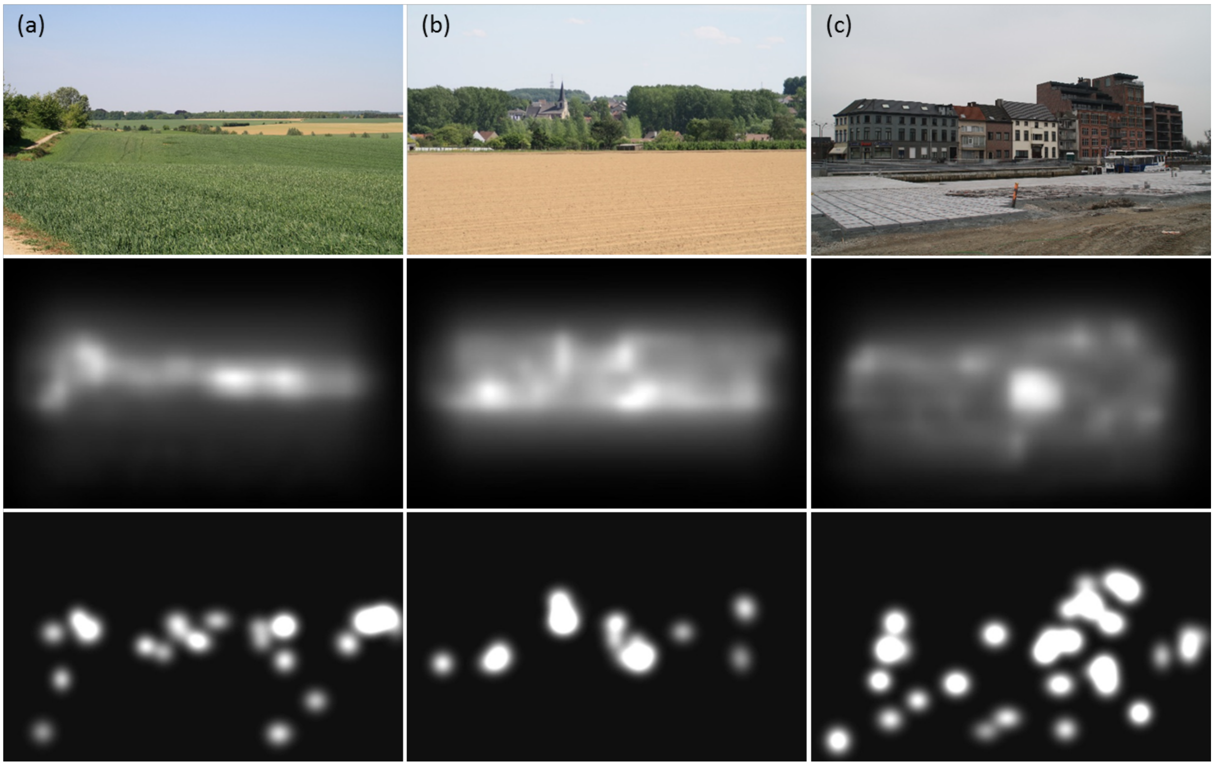

Figure 5.5 Visualisations of the saliency maps (second row) and examples of one-observer focus maps (third row) for (a) Rural, (b) Semi-rural, and (c) Urban landscapes.

In a broader context, these findings - together with the results of Dupont et al., 2015a – may point at a more general result, i.e. that buildings could be one of the determining factors guiding the observation pattern in landscape photographs. Several reasons could explain why buildings are so important in the visual exploration of the environment. First, the human eye has been demonstrated to select areas in an image containing a maximum of information (Reinagel and Zador, 1999). Salient regions with high contrast and thus high information content, like buildings in a 'green' landscape, will be fixated most (García et al., 2006). Second, the main function of selective attention is to direct our gaze towards elements of interest in our visual environment (Hikosaka et al., 1996; Braun and Julesz, 1998). From an evolutionary point of view, these elements may be determined by the Prospect-refuge Theory formulated by Appleton (1975). In particular, this theory states that all creatures, including humans, unconsciously and instinctively perceive their environment in such a way that environmental information is obtained and stored in a form, which allows an easy and quick retrieval when needed to ensure survival. This form consists of classifying the landscape according to potential prospects and refuges. Prospects are defined as places, which offer an unimpeded opportunity to see, whereas sites providing the opportunity to hide from and protect against potential hazards are called refuges. The ability to see without being seen is important in determining one's survival prospects (Appleton, 1975). Numerous examples for refuges can be mentioned but the most common concept of a refuge for modern man is a building (Appleton, 1975). Finally, because of their sharp vertical edges, buildings have high contrasts with their surroundings and could therefore catch more attention. This is related to the Gestalt principle of continuation, which states that people tend to continue shapes beyond their ending points (Koffka, 1935). When a landscape is 'interrupted' by a sharp edge, for instance of a highly contrasting building, the continuation is broken. This might result in an increase in the attention spent on this area.

The exceptionally low correlation found between the saliency and focus maps for the rural landscapes could be explained by the more monotonous character of these landscapes and thus by their low information content. This may cause boredom with observers, who may start looking around in order to find more interesting objects to fixate upon. The result is a less structured and more scattered and thus less predictable observation pattern (Dupont et al., 2015b; Figure 5.5).

5.4.3 Implications/possibilities/usefulness for visual impact assessment

According to García et al. (2006) three aspects need to be taken into account when building in relation to landscape: the landscape value, the location of the new project and the visual characteristics of the existing landscape (e.g. colours, textures, lines etc.). We believe that our methodology (see further) can be particularly useful for evaluating the third aspect: the integration of a project into the landscape once a location has been selected. García et al. (2006) recommend a detailed study of the scene in which the construction is to be executed, including an analysis of the colours, textures and lines of the main elements. As such, the design of the new development can be tuned to the existing landscape in order to attain an optimal visual integration. The main guidelines described by García-Moruno et al. (2010) consist of avoiding sharp colour contrasts, introducing vegetation cover if necessary and be careful with vertical shapes as these catch more attention (Español, 1995), especially when exceeding the skyline. These aspects (colour, orientation and brightness) are all taken into consideration in saliency images. Therefore, the method described below could be a promising tool for visual impact assessments.

In the ideal situation, a visual impact assessment is performed at the beginning of a project, before the final decision is made and before the actual works start on site. Computerized visualisations are often used to conceptualize the possible alternatives of a project (Lange, 1994; Pullar and Tidey, 2001). For new constructions, for example, different designs varying in form, scale, colour, materials and texture, can be evaluated (see e.g. VIA in the UK) in order to determine which design attains the optimal visual integration in the surrounding landscape (García et al., 2003, 2006; García-Moruno et al., 2010). Doing so prevents new constructions from visually violating the landscape, which occurs when the contrast between the new element and its surroundings is too large or when the new object simply defies the gist of the scene. However, this kind of assessment – and the consideration of visual aspects in the planning process in general – is rarely done (Lange, 1994; Schmid, 2001), and certainly not in an objective and quantifiable fashion (Hernández et al., 2004; Möller, 2006). When performed, several computer-aided simulations of a project are generally produced and a photograph-based survey is conducted to choose the best option according to the opinion of experts, focus groups or – in the best case – the public (Palmer, 2015). However, this methodology is money- and time-consuming and it is often difficult to obtain a representative public opinion and reach consensus between public and experts. But above all, a clear, quantitative and objective methodology and/or guidelines (independent of the experts/planners) are missing (Lange, 1994; Uzzell and Jones, 2000; Minelli et al., 2014; Palmer, 2015). Consequently, in many countries, visual impact assessment caused by the design of the construction is not even compulsory, while for landscape quality control it is an indispensable step in the planning process (Lange, 1994; Schmid, 2001). Saliency maps could help to resolve this issue as they offer a number of advantages that could contribute to set up a standardized and transparent methodology for visual impact assessment.

The GBVS algorithm applied on landscape photographs allows the creation of saliency maps in an easy way. As demonstrated by the correlation coefficients, these maps are positively correlated with focus maps obtained from eye-tracking the viewing behaviour of a number of observers while free-viewing these photographs. Both identify features in the landscape scene which act as eye-catchers. Saliency maps can therefore be regarded as predictions of the human viewing pattern in landscape photographs. Objects which are indicated as salient in the saliency map, will have very high changes of catching the attention in practice, while non-salient elements will not. Since it has been demonstrated that when the visual perception of a construction is reduced, its visual impact is diminished too (Hernández et al., 2004), saliency maps have a potential to be used as a new objective tool for visual impact assessment. They could be used to evaluate the visual impact of different designs or scenarios of a new construction represented in a series of simulated photographs, showing the degree of integration in the existing landscape or the potential of creating new eye-catchers that will affect human perception and viewing behaviour. By comparing the saliency map of each simulation with the saliency map of the original landscape image, an objective measure can be obtained of how salient or eye-catching the different designs of the new object will be. In particular, the correlation between the saliency map of a design simulation and the saliency map of the original landscape photograph can be calculated using the method presented in this paper. When this procedure is repeated for all potential designs, a ranking can be drawn up indicating which designs approximate the original landscape most (highest correlation) and which deviate from the existing landscape (lowest correlation). As such, the visual impact of the different design options can be compared. High correlations mean that there will not be large differences in saliency after inserting the new object and thus that the viewing pattern will not be affected. In this case, the new project will be well integrated into its surrounding landscape, will not catch the attention and thus will have a low visual impact. Low correlations reflect modifications in the saliency of the scenery after the new construction was inserted. As a result, the viewing pattern will change as well. Most probably, the new object will be more salient than the original landscape and will as a consequence catch the attention. As a result, the visual impact of the new development will be high, for example due to too sharp colour, texture or shape contrasts, which have been demonstrated to strongly influence the fixation pattern (Underwood and Foulsham, 2006; Becker et al., 2007). Simulations generating low correlation coefficients will therefore not be visually well integrated into the existing landscape.

This method is fast and easy and it allows a quantitative and scientific measure of the visual impact, which is widely demanded (Uzzell and Jones, 2000; Pullar and Tidey, 2001) as it facilitates the decision making in choosing between different designs. Scenarios or designs having a high correlation with the existing landscape photograph, will have a low visual impact and will be well integrated into the scenery. It should be noticed that the method can also be used in the opposite case, e.g. when a design is intended to act as a landmark and thus needs a high level of conspicuity. In this case, the design with the lowest correlation corresponds to the highest visual impact.

5.4.4 Recommendations for applying the methodology in visual impact assessment

First, there is a large variety of saliency algorithms available, each with their own nuances and specifications (see Borji et al., 2013b for an extensive review and comparison). However, when applying the methodology in visual impact assessment, we strongly recommend using the GBVS algorithm for several reasons. The algorithm is freely available and easily accessible, which is not the case for other algorithms. But what is more important, our study demonstrates that in the specific case of landscape photographs, the correlation between the GBVS and human focus maps is relatively high and significant, which makes the GBVS a valid and suitable prediction of the human viewing pattern and thus suitable for use in visual impact assessment. While this might also be the case for other algorithms, this has not been tested yet and thus remains uncertain.

Second, top-down influences can never be completely excluded, even in free-viewing conditions (Parkhurst et al., 2002). For example, the observer's interest, gender, mood or cultural background may affect the eye movements (Borji et al., 2013). As a consequence, the viewing pattern of one observer will never be identical to the observation pattern of another observer. This also means that the focus map of one person can correspond more to the saliency map than the focus map of another person. Saliency maps can thus not be considered as predictions valid for *all* possible observers. However, as they make predictions of the viewing pattern purely based on bottom-up principles of attention guidance, which are unconsciously effective in each human being, saliency maps can be seen as useful predictions for *most* observers, at least in free-viewing conditions.

Third, the atmospheric and weather conditions under which a photograph has been taken, will affect the saliency. Pollution, fog or rain can decrease overall contrast and thus decrease the saliency of all objects. Atmospheric attenuation increases with the distance to the objects viewed, which will become hazy, fuzzy and bluish, and details will fade out. In sunny weather conditions on the contrary, the contrast of colour and brightness will be enhanced, which increases the saliency and thus the visual attraction (García et al., 2006). In addition, the contrast will vary according to the relative position of the photographer and the sun. This is important when assessing the visual impact of objects from different viewpoints (Bishop, 2002). Photographs taken without direct sunlight have the most homogeneous contrast distribution and will therefore attain comparable saliency values. In order to be comparable, the different designs of a new construction need to have similar illumination conditions as the original landscape photograph.

Considering all these concerns, it is recommended to take the photographs under the most habitual observation conditions concerning weather and distance. Similarly, taking the photographs in one season is recommended. In usually cloudy regions, images should reflect this type of weather. The images should also be taken from points where people actually pass (e.g. roads, paths, vantage points, residential areas etc.) and from where the new planned object will be seen (see also Palmer, 2015). As such, the distance can be determined as well (García-Moruno et al., 2010). Optimally, multiple views from where the project can be seen should be included in the assessment. Of course, the view from which the construction will be most seen can receive a larger weight in the final decision.

Finally, biasing the saliency of the planned object because of improper simulation techniques should be avoided (see Sheppard (1989) for proper simulation methods). Inserting shiny elements in a shaded area in the scene will, for example, cause these objects to be incongruent. As a consequence of too sharp colour and brightness contrasts, erroneously high saliency values will be obtained indicating a high visual impact while in reality these elements might not at all catch the attention.

5.4.5 Further research

The methodology presented in this paper must be considered as a first step in assessing visual impact and, in a broader context, as a contribution to the development of a method aimed at assessing acceptability of projects.

Our methodology needs to be validated by applying the saliency method on real simulations, differing in degree of visual impact. This visual impact can be determined by analysing observer's viewing patterns to check which alternative is most eye-catching. As such, we can analyse if the most salient alternative indeed generates the lowest correlation and vice versa. However, different alternatives of a project are not always provided by the developer or the alternatives are not elaborate enough to create proper simulations of it. In this case, when comparing alternatives is not possible, it is difficult to determine if the proposed scenario will be visually integrated enough to be approved or not. A threshold for evaluating the correlation would resolve this issue and help policy makers decide on the approval of a project. However, for determining this threshold, more empirical research is needed. In particular, proposed simulations need to be developed and tested with eye-tracking and/or based on saliency maps in order to know which alternatives catch most attention (viewed first). In addition, people's opinion about how well they think the project is visually integrated into the existing landscape must be probed (for example like proposed by Palmer, 2015) as it is important to know how well the objectively measured visual impact (eye-tracking or saliency maps) is related to human judgments of visual integration. The same steps can be repeated with photographs from executed projects which have already been built. Subsequently, the correlation with the existing landscape can be calculated for the saliency maps of the simulations and executed projects. When both, the correlation coefficient and the ratings/viewing pattern of the observers are compared for a large number of projects, it is possible to determine from which correlation threshold a project can be considered to be visually integrated into a landscape. By including people's evaluation, this method could contribute to the more general concepts of landscape quality and acceptability.

Finally, at the moment, the GBVS code is only available for Matlab, which is an expensive mathematics software package not commonly accessible for most landscape architects. If our approach is to be used by landscape planners and architects it should be made more accessible. A solution would be to translate the Matlab-code into a Python-code, which can then be implemented in ArcGIS, a software program more often available to landscape professionals. The same Python-code can also be used in QuantumGIS, which is a free and open source geographic information system and for this reason even more accessible. This would largely improve the ability to use the approach presented in this paper.

5.5 CONCLUSIONS

The GBVS algorithm allows to produce saliency maps from landscape photographs in an easy fashion, at least when Matlab is available. These saliency maps have been demonstrated to be correlated with focus maps obtained from eye-tracking the viewing pattern of a number of observers while free-viewing landscape photographs.

Thus, saliency maps can be considered as predictions of the human viewing behaviour, showing potential focus areas and identifying the features in a scene that will attract the attention. While the method still needs to be validated, we believe that saliency maps could be a promising tool for visual impact analysis in landscape architecture and design, urban planning and environmental impact assessment. Saliency maps from different simulations can be made and compared to the photograph of the original landscape. The correlation between the saliency maps of the simulation and the original photograph will then indicate the degree of integration in the existing landscape, offer a quantitative measure of the degree of visual impact of different features, and help to select the best scenario for a given purpose. For example, different simulations of one project could be examined and the least salient option will then represent the most optimal visual integration into the existing landscape.

Furthermore, the correlation between the saliency and focus maps seems to vary with the proportion of buildings visible in the photographs, suggesting a relation with landscape type and degree of urbanisation in particular. Our study points out that the prediction of the saliency maps increases when the amount of buildings in a landscape photograph decreases. The human viewing behaviour is thus best approximated in rural landscapes with a limited amount of built content. This means that the methodology for visual impact assessment presented in this paper will probably be more reliable when a new construction is to be executed in relatively rural landscapes. In more urbanised landscapes, this reliability will probably slightly drop as the correlation between the saliency maps and the human focus maps is a bit lower in this kind of landscapes. Nevertheless, all the landscape categories tested in this study generated relatively high correlations between the saliency maps and the focus maps, which we believe is sufficient to confirm their validity for visual impact assessment. While this methodology is relatively easy to execute and produces an objective measure of visual integration, more research is required in order know more about the feasibility and effectiveness when working with edited photographs. A trial-and-error study should be executed to answer a number of practical questions and address the potential teething troubles of the methodology.

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CHAPTER 6: TESTING THE VALIDITY OF A SALIENCY-BASED METHOD FOR VISUAL ASSESSMENT OF CONSTRUCTIONS IN THE LANDSCAPE

Modified from:

Dupont, L., Ooms, K., Antrop, M., Van Eetvelde, V. (2016c). Testing the validity of a saliency-based method for visual assessment of constructions in the landscape, Landscape and Urban Planning, submitted.

ABSTRACT This paper aims at evaluating a method for objective visual assessment of new constructions in the landscape based on saliency calculations as proposed by Dupont et al. (2016a) (Chapter 5). Photographic simulations of buildings, towers and masts inserted in a rural environment are created in different designs, colours and sizes. Their corresponding saliency maps, which are computationally generated predictions of the human viewing pattern, are calculated and compared with the saliency map of the original landscape photograph through a correlation analysis. Higher correlations indicate a smoother visual integration from a landscape point of view of minimizing the visual disturbance. The method can, however, also be used to generate eye-catching designs such as landmarks. The output of the saliency method is compared to human assessments of visual integration obtained using a photo-questionnaire. The results demonstrate that the saliency method is sensitive to differences in colour and size. In addition, the outcome is consistent with people's subjective assessments. For design differences, this is less the case, probably because more factors than just the visual aspect are involved when choosing a design. The method is fast and easy which allows the assessment of many different scenarios and viewpoints in the early stages of the design process. This is an asset for landscape planning and design where time is money. Full automatization of the calculation procedure is the next step in the research. More empirical tests are also required to determine the method's validity in more urban landscapes.

KEYWORDS: Photographic simulations, rural landscapes, photo-questionnaire, saliency maps, correlation analysis, landscape planning and design.

6.1 INTRODUCTION

Within society there is a growing awareness of the importance of landscape quality (Tassinari et al., 2007). This quality is determined by different aspects comprising nature conservation values, agricultural and forestry values, water resources, cultural heritage, residential values and visual quality (Wu et al., 2006). This latter aspect is to a high degree controlled by human intervention in the landscape, which can greatly affect or even alter its visual quality, especially in rural environments. Therefore, architecture is considered as a key component in safeguarding the landscape's visual quality. Harmonious developments of diversity and uniqueness which take into account the historical significance and landscape character of a region are stimulated (Tassinari et al., 2007). When designed and built in harmony with the surrounding landscape, particularly remote rural buildings can be used as a means of enhancing the visual quality of the landscape (Rodríguez and Martín, 2011). According to Rodríguez and Martín (2011), landscape integration is described as 'making something become part of a whole'. As such, integration entails the adaptation of an object or territorial action to the physiognomic characteristics of the landscape or to some of its components used as a reference. However, clear, standardized and uniform methods to help integrating a construction into the landscape are not well established yet (Lange, 1994; Uzzell and Jones, 2000; Tassinari et al., 2007; Fabrizio and Garnero, 2012; Minelli et al., 2014; Palmer, 2015) as a consequence of the lack of solid theoretical approaches of the topic (Rodríguez and Martín, 2011).

In this respect, research has been conducted to assess the visual impact of a construction in terms of its *visibility* by mapping the area in which the construction will be visible (e.g. Burrough, 1994; Fisher, 1996; Hernández et al., 2004; Möller, 2006; Rogge et al., 2008; Nijhuis et al., 2011; Minelli et al., 2014). This is often carried out in a Geographic Information System by performing a viewshed analysis to determine the most suitable location for the development of the new construction, i.e. the location with the lowest visibility (smallest viewshed) (Bishop, 2003). However, such assessment do not take into account the *visual characteristics* of the construction in terms of lay-out and design, and can therefore not be used to evaluate the visual integration in the surrounding landscape. This kind of visual integration has not been extensively investigated within the field of science. Studies concerning visual integration in an urban environment are very scarce (e.g. Unver and Ozturk, 2002; Sumper et al., 2010). In rural landscapes, visual integration research has mainly focused on agricultural buildings (e.g. Di Fazio, 1989; García et al., 2003, 2006; García-Moruno, 2010; Hernández, 2004), greenhouses (e.g. Rogge et al., 2008) and renewable energy infrastructures such as wind-power plants (e.g. Ladenburg, 2009; Minelli et al., 2014; Palmer, 2015) and photovoltaic plants (e.g. Chiabrando et al., 2011; Minelli et al., 2014) but far less on residential buildings (e.g. Tassinari, 2007). As a consequence, procedures and instructions for visual integration have not been implemented in the general practice of spatial planning (Lange, 1994; Schmid, 2001; Tassinari et al., 2007).

This evolution might have – and in many cases already has – considerable effects on the visual quality of the landscape as buildings can cause significant transformations (Tassinari et al., 2007). Especially poor and landscape-unaware designs are very likely to detract from the visual quality of the landscape. According to Tassinari et al. (2007), recently erected and contemporary rural buildings are often characterised by poor architectural quality. In addition, the phenomenon seems to be widespread in Europe (Tassinari et al., 2007). This is probably due to the lack of compulsory visual impact assessments in spatial planning in combination with money-saving decisions made by contractors. For example, in order to reduce the design and building costs, uniform design concepts using prefabricated components are often chosen. However, these predominantly focus on functionality without leaving room for considering the unique characteristics of the site or the surrounding landscape from a landscape point of view of visually integrating the construction into its surroundings (Schmitt, 2003). This entails a real risk that in the end – if not yet – cost reduction will overrule any concerns regarding the visual impact on the landscape, leading to a systematic ignoring of the issue of visual integration (Tassinari et al., 2007). In order to turn the tide, more efforts should be made to establish methods, based on scientific research, which can be used to easily evaluate the visual integration/impact of new or modified constructions on the landscape before they are (re)built.

As the visual impact caused by the characteristics of a construction is rarely evaluated (Hernández et al., 2004), we proposed a method to objectively quantify the degree of visual integration of a construction in the landscape (see Dupont et al., 2016a). In summary, the method consists of creating saliency maps for photographic simulations of a new project. These are computationally generated images which encode for salience at each location in an image based on the image's characteristics in terms of colour, orientation and intensity information (Itti and Koch, 2000, 2001; Itti, 2005; Peters et al., 2005). As such, saliency maps identify the features in an image which are most likely to catch the attention. As saliency maps have been demonstrated to be reliable predictions of the human viewing pattern in landscape photographs (Dupont et al., 2016a), they can be used to identify how eye-catching different scenarios of a construction will potentially be. The scenario which least captures people's attention is likely to be the best integrated from a landscape point of view of minimizing visual disturbance (Dupont et al., 2016a). In the opposite case, the method is also useful for determining the most eye-catching scenarios which can be important for designs which are meant to be a landmark or statement from a designer/architect point of view.

The aim of this paper is to evaluate this saliency-based method for assessing the visual integration/impact of a construction in the landscape by applying it to a number of photographic landscape simulations. The comparison of the results found for different simulations of the same construction allows us to determine whether the method is sensitive to these different scenarios. In addition, the results are compared to human judgements of the visual integration of the simulated constructions.

6.2 METHODS

6.2.1 Creation of the simulations

6.2.1.1 Photographic stimuli

Ten landscape photographs were taken in rural areas in Belgium. To obtain comparable images, the same routine was repeated when taking the photographs. The images were all taken with a Canon EOS 1000D camera using a focal length of 50mm to assure that equal visual angles were obtained. Furthermore, a tripod was used to achieve a constant camera height of 1.70m. The horizon was always placed in order to generate pictures with a composition of 2/3 of land and 1/3 of sky. Finally, all photographs were taken in similar weather and seasonal conditions.

6.2.1.2 Simulations

Of each landscape photograph, simulations were created in GIMP, a free-access photo-editing software package. An object that could either be a tower, a building or a mast was inserted into the image. Of each object, three different designs were simulated as realistic as possible. The illumination conditions of the inserted element were geared to the conditions in the original photographs and shadows were added where necessary. This procedure generated 30 simulations in total: in four landscapes a building was inserted, in three a tower and in three a mast.

In a second step, two additional simulations, in which the size of the object was varied, were created for each of the 30 simulations. Variation in size was chosen as this variable has been identified as essential in determining the visual impact of a construction (Rodríguez and Martín, 2011; Curado and Marques, 2012). More specifically, a smaller and a bigger version of the object was inserted into the landscape photograph. To assure the comparability of the simulations, the location of the object in the images was kept constant for all sizes. In total, 60 additional simulations were obtained (10 landscapes x 3 designs x 2 sizes).

In a last step, the colour of the simulated construction was altered since colour, and more specifically colour contrasts between an object and the background, is considered to highly affect the visual impact (Di Fazio, 1989; Cañas-Guerrero and García-García, 1994; Fabrizio and Garnero, 2012). Therefore, three colour versions were created for each of the initial 30 simulations (mid-size) besides the original colour of the object. A first version consisted of colours that are matching the background colours of the surrounding landscape. In the second version, one striking, bright and highly contrasting colour was chosen for the entire object. In the last version, the inserted element was coloured into several different eye-catching colours not matching the surrounding environment. These simulations were not created for 2 of the 3 landscapes in which a mast was inserted, since this type of construction was too thin to be coloured in a noticeable fashion. This methodology thus resulted in 72 additional simulations (8 landscapes x 3 designs x 3 colours).

In total, besides the 10 original landscape photographs, 162 simulations were used in the photo-questionnaire.

6.2.2 Saliency-based analysis

6.2.2.1 Creation in Matlab

For each original landscape photograph and each of the simulations, a saliency map was created, resulting in 172 saliency maps. This was done in the Matlab software package using the Graph-based Visual Saliency (GBVS) algorithm developed by Harel et al. (2006), which is freely available on http://www.klab.caltech.edu/~harel/share/gbvs.php (Harel, 2012). This algorithm was chosen as it has been demonstrated to be the algorithm that most reliably predicts the human viewing pattern in environmental scenes (Borji et al. 2013) and in landscape photographs in particular (Dupont et al., 2016a).

6.2.2.2 Correlation between the original image and the simulated images

The Pearson correlation coefficient was calculated between the saliency maps of the original landscape photographs and the simulated photograph. This was done according to the procedure as described in detail by Dupont et al. (2016a). Briefly summarized, each saliency map was transformed into an ASCII-table containing the greyscale values of each pixel, which were then rearranged into one column per saliency map. As such, a dataset was obtained containing the values of the saliency map of the original photograph as well as the values of the saliency maps of all the simulations (design, size and colour variations).

Subsequently, this dataset was imported in SPSS to calculate the Pearson correlation coefficient between the saliency maps of the original image and the saliency map of each simulation. As such, 18 correlation coefficients were obtained for each original landscape photograph (3 designs (midsize and original colour) x 2 additional sizes x 3 additional colours). As mentioned before, no colour simulations were produced for two landscapes in which masts were inserted. In consequence, no correlation coefficients could be obtained for these landscape photographs.

To determine if the saliency-based method is able to detect significant differences between simulations of different size or colour, a Friedman and Wilcoxon Signed Rank test was performed. In particular, the test aimed at determining if there is a significant difference in correlation coefficient between the different sizes (small, midsize and large) and colours (original colour, integrated colour, one bright colour, multiple bright colours). In order to overcome the non-additive property of the raw correlation coefficients, which for example does not allow to calculate a mean value, a Fisher's Z transformation was performed onto the coefficients (Sheskin, 2003) before the statistical tests were performed. The results are visualised in bar graphs depicting the mean correlation coefficient (after the Fisher's Z transformation) for each class of size and colour.

This analysis could not be performed for the simulations differing in design since these could not be unequivocally classified as 'design 1, 2 or 3' because they vary for more than one parameter (e.g. not only size but also colour, shape, texture etc.) and these parameters are variable from design to design and from landscape to landscape. What is classified as ‘design 1’ in landscape 1 has not necessarily the same characteristics as ‘design 1’ in landscape 2, 3, 4 etc. The classification into design 1, 2 or 3 is thus not based on a set of parameters which are equal for all the designs in one group (e.g. design 1) but instead is ad hoc. One design could equally be designated as ‘design 1’, ‘design 2’ or ‘design 3’. Performing a Friedman test would not make sense as this test compares all ‘designs 1’ to all ‘designs 2’ and all ‘designs 3’, which is a useless effort considering that the groups are randomly classified. Instead, a more qualitative approach was used to determine whether the correlation coefficients were found to vary between the different designs. In particular, the correlation coefficients for the three designs were visualised in separate bar graphs generated for each photograph (10 in total), assessing the differences in correlation coefficients without testing their significance. A qualitative comparison with the corresponding graphs containing the results of the photo-questionnaire, however, could still be performed (see section 6.2.4).

This whole procedure provides a first indication of the method’s validity and usefulness. A second step in testing the proposed method consists of comparing these results to people’s estimation of the visual integration of each simulated object (see section 6.2.4 for further details).

6.2.3 Photo-questionnaire

6.2.3.1 Content and task

The photo-questionnaire was set up using Acrobat Reader Professional XI. On the first page, a brief description of the task was given as follows:

“Please classify the three or four simulations according to their visual integration in the landscape (How well does the construction fit into the landscape?).

1 = lowest integration (worst fit; the construction is most disturbing)

2 = medium integration (the construction is not well integrated but is not disturbing either)

3 (or 4) = highest integration (best fit; the construction is best integrated and is most in harmony with the landscape)

For each series of simulations, the numbers 1,2 and 3 (and 4) can only be picked out once each. You thus need to classify the simulations from low to high integration. No cases can be left empty."

To illustrate and clarify the task, an example was included (Figure 6.1) and the meaning of the scores was added to avoid misunderstandings. The questionnaire consisted of 64 pages on which each time a series of simulations needed to be attributed a score. The questionnaire was set up as follows. First, the simulations were grouped according to the varying feature (design, size or colour). For instance, three simulations in which three different buildings were inserted in the same landscape photograph were placed together on one page of the questionnaire (Figure 6.2). The same was done with the simulations varying in size (small, midsize and large version) (Figure 6.3) and in colour (4 different colour versions were put together) (Figure 6.4). For each image, a dropdown menu was added so that respondents could either chose to score the simulation 1, 2, 3 (or 4). Additional to each simulation series, the actual untouched landscape photograph was provided to give the respondent an idea of what the actual landscape looked like. In total, 64 simulation series (10 varying in design, 30 varying in size and 24 varying in colour) were created. In the final questionnaire, the order of the simulations in each series, as well as the general order, was randomized.

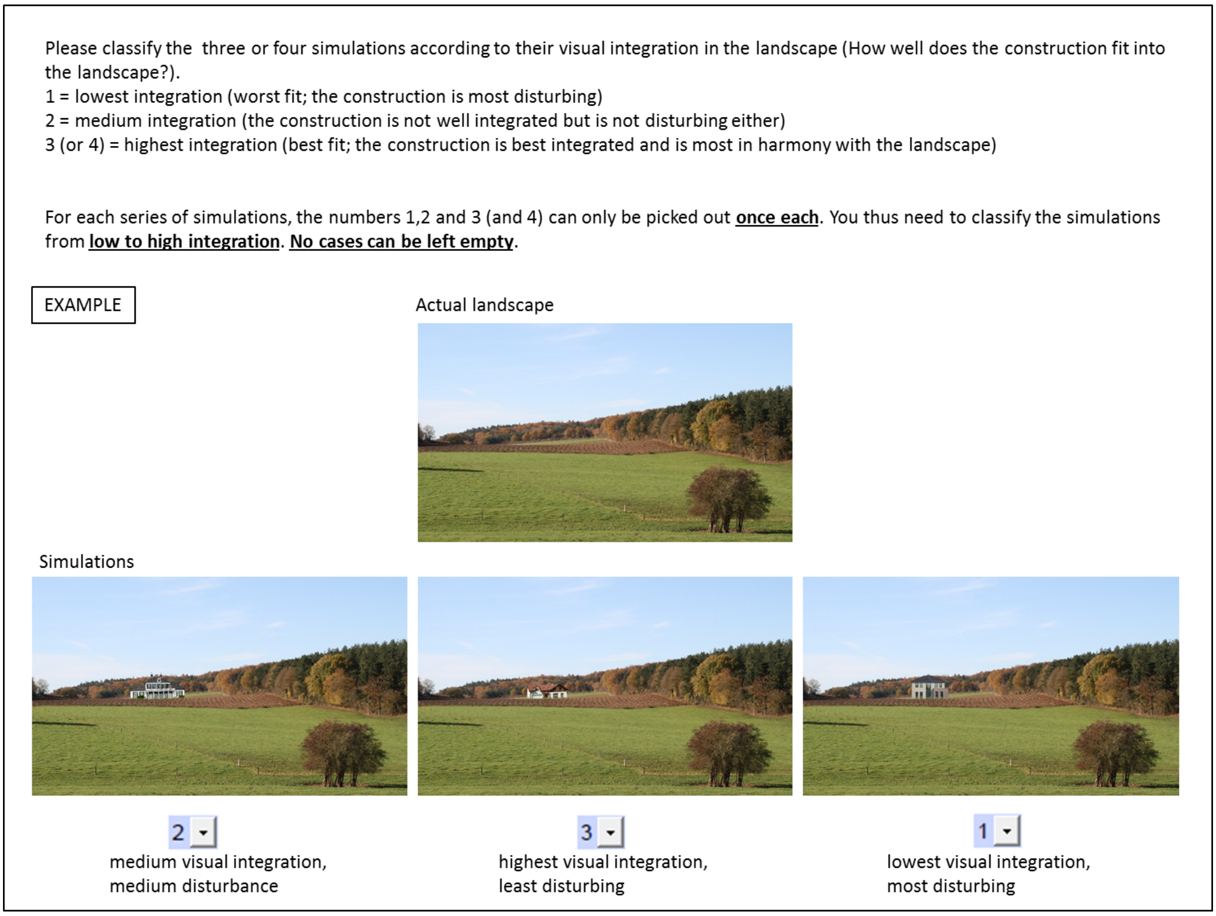

Figure 6.1 Task given to the respondents for ranking the simulations, including an example added for clarity.

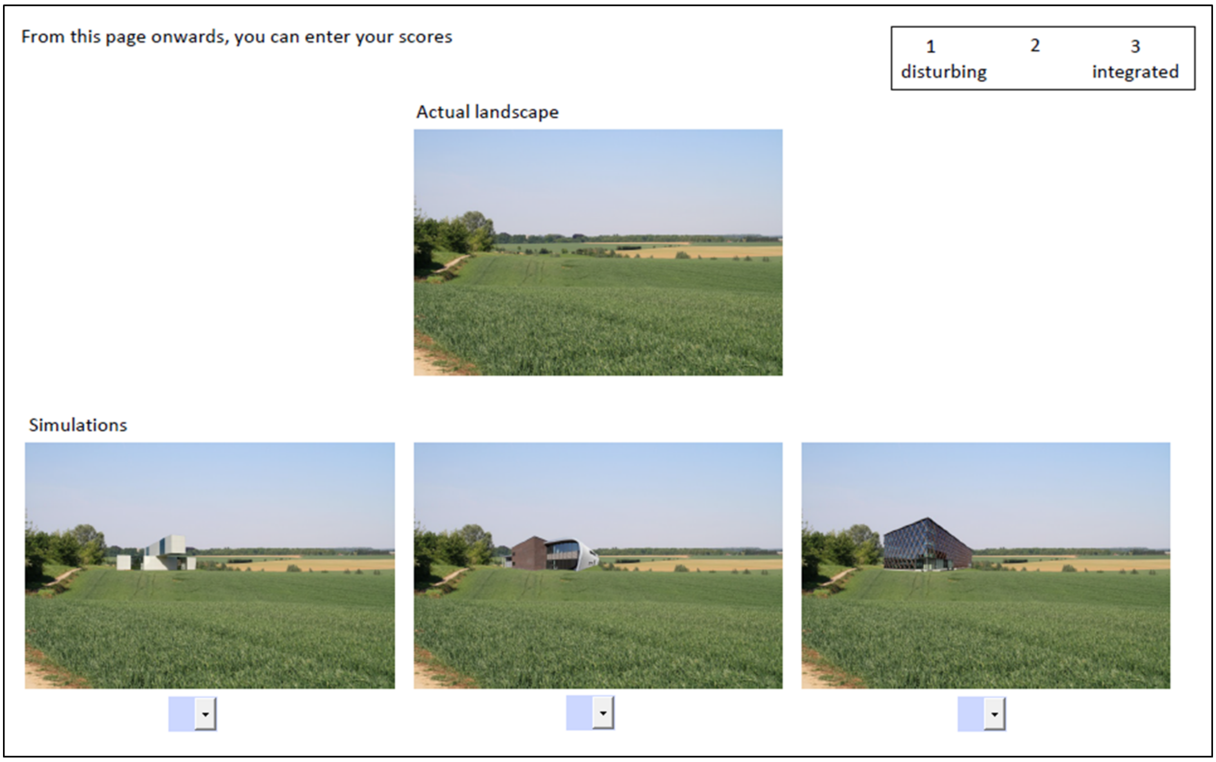

Figure 6.2 Example of a simulation series differing in design.

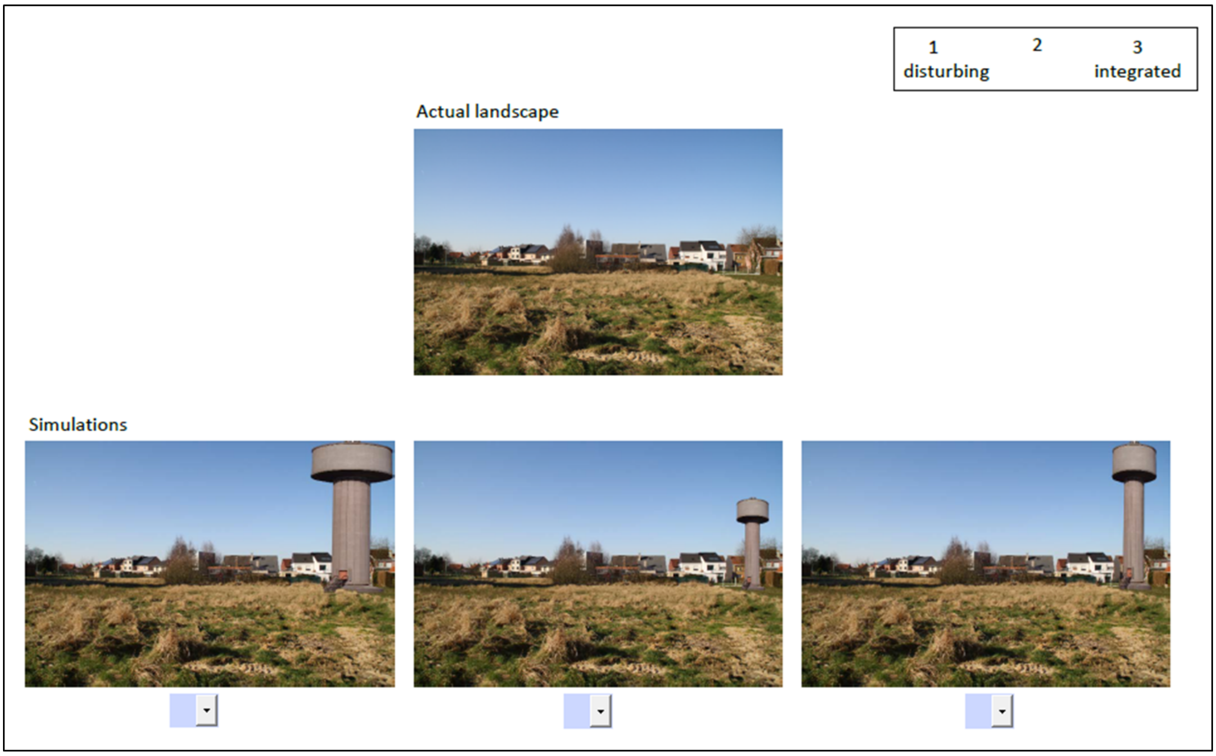

Figure 6.3 Example of a simulation series differing in size.

Figure 6.4 Example of a simulation series differing in colour.

The photo-questionnaire was send by e-mail to the respondents, which were given two weeks to complete it. Once completed, the questionnaire was returned by the participants and the results were inserted into a spreadsheet.

6.2.3.2 Respondents

The photo-questionnaire was send to the whole department of Geography of Ghent University and to relatives and friends so that persons with different backgrounds were reached. In total, 37 respondents, of which 17 male and 20 female, completed the questionnaire and sent it back. When asked if there were any problems understanding the task, no issues were mentioned. All collected questionnaires were filled in properly and the data could be processed.

6.2.3.3 Processing of results photo-questionnaire

The data obtained from the photo-questionnaire were inserted in an Excel spreadsheet. The photographs were given a number and for each image, the score of each individual respondent was inserted. The mean score over all respondents was calculated, resulting in a decimal score varying between 1 and 3 (or 4 for the colour simulations). These scores were then used to calculate the correlation between the degree of visual integration as estimated by the respondents (mean scores) and the degree of visual integration as estimated by the saliency analysis (correlation coefficients) (see section 6.2.4).

A Friedman and Wilcoxon Signed Rank test allowed to determine whether the ratings of the different sizes and colours differed significantly. The mean scores were used since all simulations could be tested at once as only one distinguishing parameter (size in the first case and colour in the second) was present. As a consequence, this analysis took all simulations into account at once and compared, for instance, all small, midsize and large simulations to each other, revealing possible differences between these three groups. The means of the scores per size- and colour-category were visualised in bar graphs.

In parallel to the correlation analysis, the analysis of the design-simulations was performed differently for the reasons mentioned before (see section 6.3.1). More specifically, bar graphs for the three designs in each original landscape photograph (10 in total) showed the mean score of the respondent ratings. These indicate how different the scores between the different designs are, and allow a comparison with the graphs of the correlation coefficients (see section 6.2.4).

6.2.4 Relationship saliency score-questionnaire score

A correlation analysis in SPSS was applied to the data in order to determine how well the result obtained from the saliency analysis corresponds to the degree of visual integration as indicated by the respondents. This was performed on the correlation coefficients of each simulation obtained from the saliency comparison and the mean score of each simulation attributed by the respondents. The Pearson correlation coefficient was calculated for the simulations differing in design, size and colour separately.

In addition, the discriminating capacity of the saliency analysis was compared to that of the respondents. In particular, we were interested in knowing whether the saliency method detected the same differences in design, size or colour as the photo-questionnaire. In other words, does the Friedman and Wilcoxon Signed Rank test provide the same results when performed on the correlation coefficients of the saliency analysis and on the mean scores obtained from the respondents? Were significant differences found between the same groups?

6.3 RESULTS

6.3.1 Correlation between the original image and the simulated images

For all simulations high Pearson correlation coefficients were found, varying between 0.784 and 0.999. While the difference between the correlation coefficients of different sizes or colour within one landscape seem subtle, the Friedman test indicates a significant difference between the different size-categories and between the different colour-categories. The results are summarized in Table 6.1 and Figure 6.5 (left graphs). The 'real mean values' are the mean Pearson correlation coefficients, after Fisher's Z transformation, found between the saliency map of the original landscape photograph and the saliency map of the simulations. For the simulations differing in size, a significant difference was detected between the three categories ($P < 0.01$). The small size simulations seem to be associated with significantly higher correlation coefficients than the midsize simulations, which in turn generate higher correlation coefficients than the large-size simulations (see Table 6.1 and left column of Figure 6.5). For the four colour categories (original colour, integrated colour, striking colour I, striking colour II) a significant difference was found between the integrated colour and striking colour I and II ($P < 0.01$), which were both characterised by much lower correlation coefficients (see Table 6.1 and Figure 6.5).

Table 6.1 Results of the Friedman and Wilcoxon Signed Rank test for the saliency correlations of the scenarios differing in size and colour. The colours indicate the outcome of the pairwise Wilcoxon Signed Rank test and represent significant differences: turquoise = lowest mean rank, green = medium mean rank, yellow = highest mean rank. Grey cells indicate that there is no significant difference with any other class. N gives the number of observations.

	size					colour					
	N	Small	Midsize	Large	P-value	N	Original colour	Integrated colour	Striking colour I	Striking colour II	P-value
Mean rank Pearson correlation coefficient	30	2.70	2.00	1.30	0.000	24	2.75	3.12	2.00	2.12	0.001
Real mean values Pearson correlation coefficient		0.990	0.975	0.960			0.970	0.983	0.952	0.956	

6.3.2 Photo-questionnaire

Table 4.4 and Figure 6.5 (right graphs) visualise the results of the Friedman and Wilcoxon Signed Rank test for the respondent scores for the scenarios differing in size and colour. The 'real mean values' are the mean respondent scores as rated by the respondents. The Friedman test reveals significant differences between all categories of size ($P < 0.01$). The Wilcoxon Signed Rank test ranks the three categories as follows: small > midsize > large (see Table 4.4 and right column of Figure 6.5). For the categories differing in colour, the tests indicate a significant difference between all groups (P <

0.01). In particular, the integrated colour was rated higher than the original colour, which had higher scores than striking colour I, which finally received the lowest ratings.

Table 6.2 Results of the Friedman and Wilcoxon Signed Rank test for the respondent scores of the scenarios differing in size and colour. The colours indicate the outcome of the pairwise Wilcoxon Signed Rank test and represent significant differences: turquoise = lowest mean rank, green = medium mean rank, light yellow= second highest mean rank, dark yellow = highest mean rank. N gives the number of observations.

	size					colour					
	N	Small	Midsize	Large	P-value	N	Original colour	Integrated colour	Striking colour I	Striking colour II	P-value
Mean rank respondent score	30	2.93	2.00	1.07	0.000	24	3.08	3.79	1.92	1.21	0.000
Real mean values respondent score		2.664	2.173	1.163	0.000		3.208	3.516	1.940	1.336	0.000

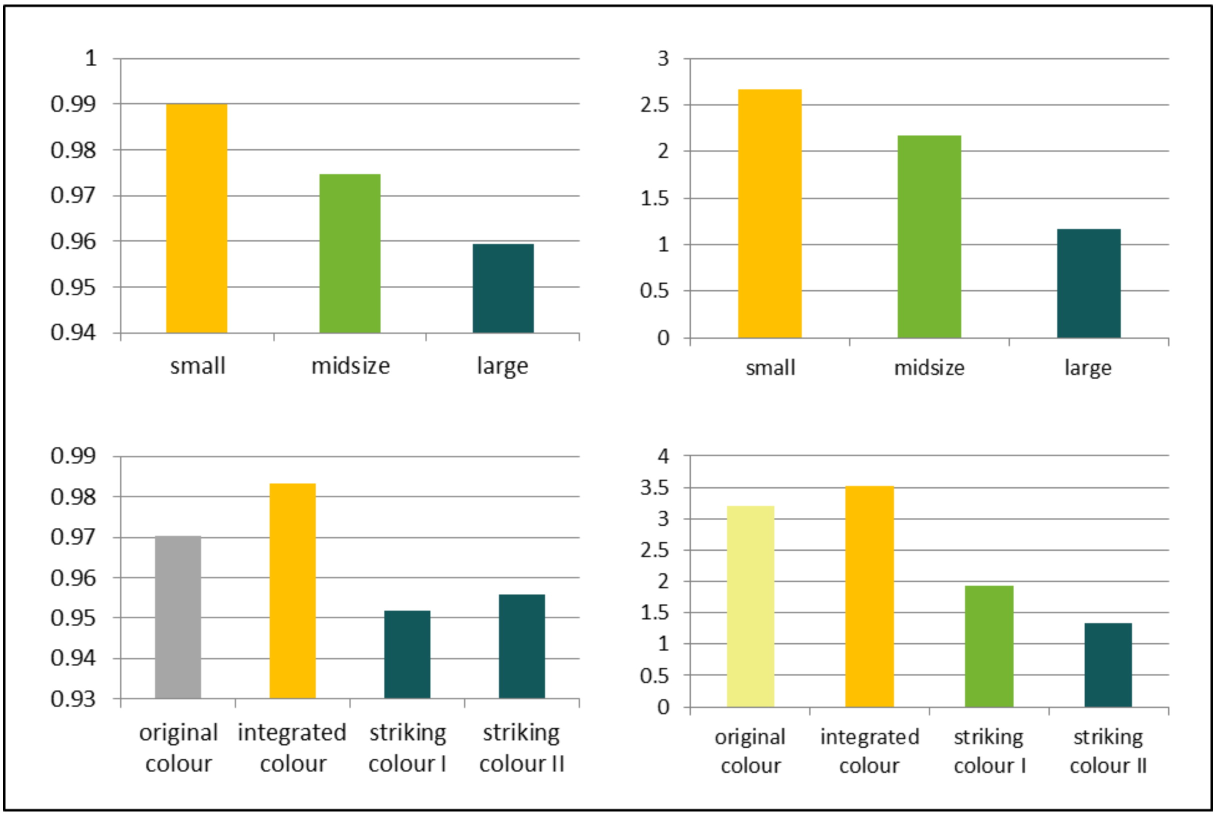

Figure 6.5 Mean saliency correlations (left graphs) and mean respondent scores (right graphs) per size- and colour-category. The colour representations have the same meaning as in Table 6.1 and 6.2.

6.3.3 Relationship saliency score-questionnaire score

The correlation analysis between the correlation coefficients of each simulation obtained from the saliency analysis and the mean respondent scores revealed the following results: for the different designs a Pearson correlation coefficient of 0.019 was found not to be significant ($P > 0.05$), for the different sizes and colours the Pearson correlation coefficients of respectively 0.360 and 0.307 were both significant ($P < 0.01$).

For the different design categories, the results were extended by a qualitative analysis for the reasons mentioned before (see section 6.3.1). The graphs in Figure 6.6 and 6.7 enable a qualitative comparison between the correlation coefficients based on the saliency maps and the mean scores given by the respondents in the photo-questionnaire. These graphs clearly show some variation between the results of both methods. For two landscapes, the saliency analysis generates the same outcome, in terms of the order in which the designs are classified, as the ratings of the respondents. In four other landscapes the highest (3) or lowest (1) scoring design is equal in both the saliency analysis and the response in the photo-questionnaire. The remaining four landscapes show no similarities between both techniques.

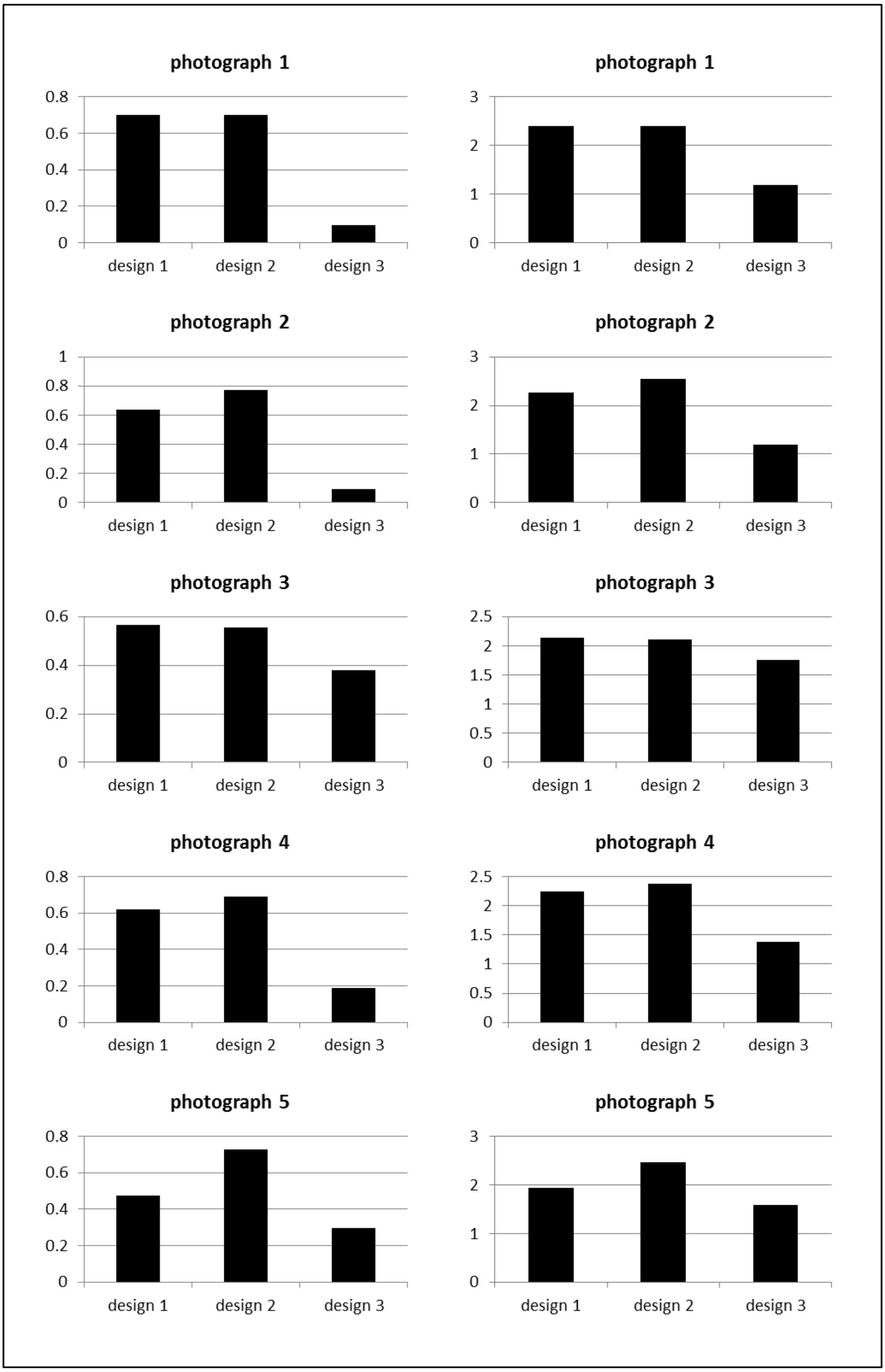

Figure 6.6 Qualitative comparison between saliency correlations (left column) and mean respondent score (right column) per photograph (1-5) for the three designs.

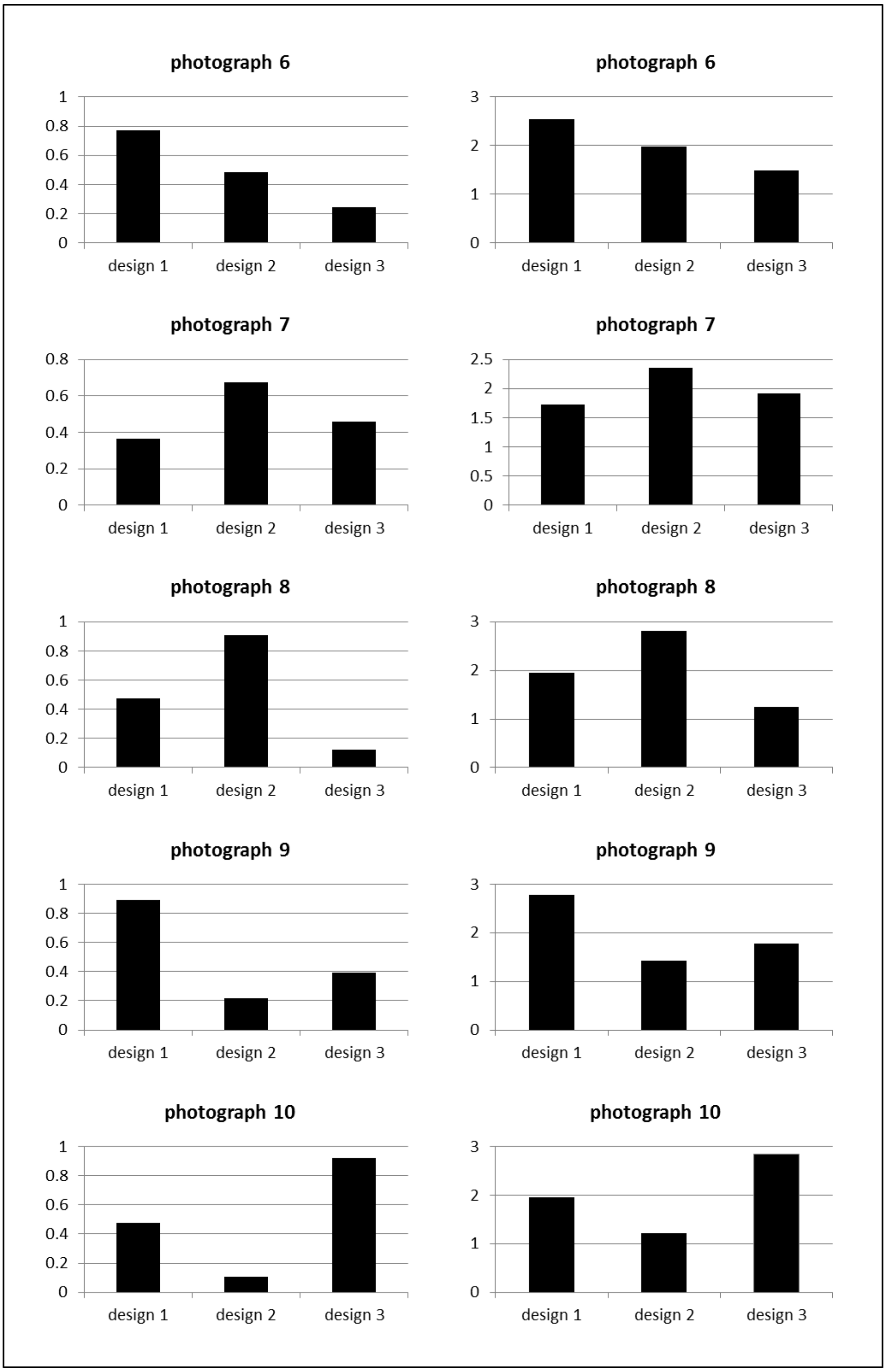

Figure 6.7 Qualitative comparison between saliency correlations (left column) and mean respondent score (right column) per photograph (6-10) for the three designs.

6.4 DISCUSSION

6.4.1 Interpretation of the results

Our method for quantifying the visual impact using saliency maps is able to detect significant differences in integration of constructions in the landscape when size and colour are varied. In addition, the results are to a large extent consistent with the assessments made by the respondents in the photo-questionnaire. The Friedman and Wilcoxon Signed Rank tests between the results obtained by the two methods generate a highly similar outcome. Both tests indicate the same significant differences between the three simulated size categories. In particular, the saliency correlation coefficients and the human rating scores decrease from small size constructions to large size constructions. This indicates that the degree of visual integration in the landscape increases when the size of the construction decreases; larger constructions are more probable to have a high visual impact and to be experienced as disturbing. These findings are consistent with earlier research which found that the volume of a construction should be of limited dimensions in order to improve its visual integration into the landscape (Rodríguez and Martín, 2011). Most important is that the saliency method proves to be a good predictor of the degree of integration of tall objects in the landscape as experienced by people.

For the colour variations, the saliency method only discriminates between the categories 'integrated colour' (showing higher correlation coefficients) and 'striking colour I and II' (lower correlation coefficients). The respondent scores in the photo-questionnaire depict a more detailed distinction. Significant differences in scores were found between all the four colour variations. The categories were classified as follows (from high to low scores): integrated colour, original colour, striking colour I, striking colour II. However, the main trend is similar in both methods: striking colours have lower correlation coefficients and are scored lower by the respondents in the photo-questionnaire than the integrated colour. The analysis suggests that the visual integration of a construction with striking colours is lower than a construction for which more harmonious colours which match the surroundings are chosen. This is in line with findings reported by Rodríguez and Martín (2011), García et al. (2006), García-Moruno et al. (2010), who conclude that the use of appropriate colours produces better integration results from a landscape perspective of minimizing visual disturbance.

The results found for size and colour variations confirm the Gestalt principles of similarity and figure-ground, operating during human perception processes. These principles respectively state that objects which look similar are perceived as a group and that humans differentiate objects from their background (Köhler, 1947). In our study, constructions with colours matching the surrounding landscape were indeed identified as less disturbing and thus more experienced as a whole with the surrounding landscape. High contrast constructions were evaluated as being disturbing. These were thus rather seen as individual, intrusive objects, standing out from their background and not being one with the landscape.

The qualitative analysis of the different designs shows less similarity between the saliency method and the photo-questionnaire. Only six out of ten landscapes are rated similarly by both methods. This is confirmed by the non-significant correlation coefficient between the saliency correlation coefficients and the mean respondent scores for the different designs. Possible reasons for this low similarity are explained in the next section (6.4.2).

One could wonder why it is important to objectively assess obvious aspects such as size and colour. However, numerous examples from real-built constructions show that common sense is not always involved, sometimes as a result of cost reduction, when choosing the size and certainly the colour of a construction (Schmitt, 2003; Tassinari et al., 2007). While the problem is widespread in Europe, especially in Flanders (Belgium), the inconsiderate architecture has led to a cacophony of styles not geared to one-another and therefore lacking visual harmony (Tassinari et al., 2007). We believe that the usefulness of the saliency method is twofold. It can be used either for the purpose of visually integrating a construction from a landscape point of view of reducing visual disturbance. Either, it can be used for visually emphasizing a construction without visually violating the surroundings as many landscape architects nowadays want to produce designs which are clearly distinguishable and unique.

6.4.2 Evaluation of the method

The degree of visual integration of constructions obtained by the saliency method is positively correlated with the respondent ratings in a photo-questionnaire, at least for the simulations differing in size and colour. This is not the case for the differences based on design (see next paragraph). Therefore, we will focus on size and colour differences first. Although a significant positive correlation was found, it is not a very strong one (0.360). A possible explanation might be found in the fact that, perhaps unconsciously, more factors are involved in human judgement concerning visual integration than only the visual aspects. Certainly, the high correlation coefficient shows the primary role of the visual aspect, but other considerations can be important assessment criteria, such as the potential use or function of the object, its accessibility, the personal aesthetic preferences, the mood of the respondent, the degree of familiarity/assimilation with the presented landscape, the historical context, the architectural style in the surroundings (e.g. Tassinari et al., 2007) etc. Examples provided by the respondents themselves. One person stated to prefer buildings having a clear path or road leading to the entrance. Another respondent mentioned that too small stables are not functional. However, the significant positive correlation between the saliency outcome and the respondent assessments points towards the dominant role of the visual aspects when assessing visual integration into the landscape. In addition, the moderate correlation indicates that human assessment is not solely based on one aspect but instead is more complex. Therefore, it is very difficult to establish a quantitative measure to predict human assessments, even if only one aspect of the landscape is probed. This study demonstrates that the saliency method is useful for visual impact assessment, but precautious interpretation remains necessary and it should not be considered as deterministic. Our saliency-based method is intended to be a helping tool in facilitating the design and decision-making process since it is fast and objective in assessing visual disturbance of planned constructions in the landscape. It is also sensitive for differences in size and colour. For the investigated cases, the method has been demonstrated to be consistent with human assessments. Both methods indicate the same scenarios as being most integrated and identify the same scenarios as most disturbing. This discriminating capacity is much more important for the saliency method to be useful than the fact that it would generate a high correlation coefficient between the saliency output and people's ratings. In the end, the main purpose of the method is to differentiate between scenarios, and not to predict the ratings of the public as correctly as possible (which in this case would generate high correlation coefficients). In other words, the relative discrimination between scenarios is of greater importance than the absolute prediction of the human ratings of the different scenarios. Since our method meets these requirements, it thus is useful, at least for evaluating colour and size differences. For design choices, it is more difficult. Concerning this aspect of a construction, the saliency method does not seem to be a reliable predictor of human assessment of visual integration/disturbance (see reasons mentioned earlier in this section). However, rarely, different designs of a construction are sufficiently developed to generate accurate simulations because it is too expensive and thus the choice of design is sometimes made without considering many alternative styles. Typically, the developer and architect create one option of design, which they believe is economically viable (Hernández et al., 2004). In the best case, small differences, for instance regarding the finishing of the construction which may comprise colour, building material etc., are compared through simulations of different scenarios of the same basic design. In this case, the saliency method can be useful to objectively compare the different possibilities.

6.4.3 Practical use of the saliency method

While the presented method has been demonstrated to be useful, some practical and critical reflections about its use should be mentioned.

Clearly, the saliency analysis is not a decisive tool, but can assists in making choices between scenarios of planned constructions by assessing their visual impact on the landscape. The final decision, however, should not be solely based on visual criteria but on many other aspects as well. The appearance and structure of a constructions should be geared to its functionality. For example, the size of a construction is related to the purpose for which it is built. Telecommunication towers, for example, need to reach a certain height in order to function properly. In this case the saliency method will probably indicate that a smaller tower is visually less disturbing for the landscape but in such cases the visual impact cannot be the dominant factor. However, designers should take care of choosing colours which should be in harmony with the landscape without camouflaging it (Rodríguez and Martín,2011; García et al., 2006; García-Moruno et al., 2010). This is where the saliency method can be helpful.

Second, the presented method does not aim at removing all creativity from the designers and architects by objectively deciding which construction should be built in which landscape and how its appearance should be. Designing should remain a creative process which leads to diversity and peculiarity. Our method is intended to be used during this process of designing, for facilitating the choices which need to be made, and not to replace it. In particular, it offers an easy helping tool to quickly make visual assessments of proposed constructions. For estimating the visual impact of one simulations, the entire procedure comprising the making of the saliency maps and the calculation of the correlation coefficient only takes a couple of minutes. In addition, higher amounts of saliency maps can be generated and processed at once, which makes it very easy to include many different simulations or simulations from many different viewpoints in the assessment. As such, a very broad estimation of the visual integration/impact of planned constructions can be obtained very quickly. This is a huge advantage as in practice, time is money. The method is also easy to perform. No high levels of expertise are required since the procedure is very straightforward, although consisting of different calculation steps performed in different software packages. Nevertheless, full automatization would make it more user-friendly and therefore, this should be a priority for further research (see section 6.4.4). Finally, the saliency method allows to minimize public consultation in this phase of the design process since it has been demonstrated to be a reliable proxy of human assessments of visual integration concerning colour and size choices. This saves time and money as public consultation is a slow and expensive undertaking.

As such, designers, planners and architects could take the visual integration of a new construction into account, without in any way omitting their own vision and creativity. The saliency method should not lead to situations in which all man-made constructions are ‘camouflaged’ into the landscape and ‘disappear’ in their surroundings. It predominantly aims at avoiding buildings or constructions in general to be defying the visual context of the surrounding landscape and be experienced as visually disturbing. Instead, the main purpose is to allow choosing the most integrated scenarios of a new project, while keeping its own features which make that it is in harmony with but still distinguishable from its surroundings, as also mentioned by Tassinari et al. (2007) and Serra (2010). It should be kept in mind that new constructions, when built in harmony with the landscape, can contribute to the landscape’s visual quality (Rodríguez and Martín, 2011). Landscape-aware designs also avoid the need to introduce camouflaging measures such as the planting of vegetation, consolidation of slopes, installation of fences along roads (e.g. Rodríguez and Martín, 2011; Curado and Marques, 2012). While such measures are intended to reduce the visual impact of a construction, they are nevertheless often experienced as intrusive and not in harmony with the landscape and therefore fail to contribute to the visual landscape quality.

Finally, it should be mentioned that the need for visual landscape integration also depends on the landscape management strategy of the area. Depending on whether this strategy is oriented towards protection of the quality of the landscape, improvement of the landscape which is subject to a certain degree of alteration, recovery of the landscape after degradation or creation of a new landscape (Rodríguez and Martín, 2011), visual integration of new construction could either be stimulated or tempered to enhance its conspicuity. While in high quality landscapes and in landscapes which need improvement visual integration will be maximized, the aim of ‘integration’ in recovering or new landscapes could be to accentuate new construction in order to contribute to the landscape's new identity (Rogge et al., 2008; Rodríguez and Martín, 2011). For this purpose of creating eye-catchers (e.g. landmarks), our saliency based method could be used as well, while this needs further investigation first. Such designs need to be very eye-catching and highly contrast with their surroundings. However, at the same time they need to be an improvement for the landscape and add value to it. While the saliency method can be used to choose the most eye-catching scenario, this should be done carefully as too striking colours or too many different colours, which will be most eye-catching according to the saliency method, might be experienced as disturbing as pointed out by our photo-questionnaire (striking colour I and striking colour II). Designers and planners should not blindly rely on the saliency method but instead keep using their common sense in order to assure the landscape quality, while delivering an eye-catching design.

6.4.4 Recommendations for further research

In this paper, we tested the validity of our method for visual integration assessment of new constructions as presented by Dupont et al. (2016a). While we applied the method on a considerable amount of photograph simulations – which generated positive results – a number of issues still need to be investigated in order to make the method more user-friendly and reliable.

First, research should be performed to automate the saliency method's calculation procedure. While it now consists of different but easy steps, executed in different software programs, it could become more user-friendly if the entire calculation could be done at once using one software package. As such, the necessary use of expensive software packages such as Matlab and SPSS could be avoided, which would make the method more accessible. This requires elaborated programming research in order to include all the different calculation steps into one script.

Second, further research is necessary to confirm the validity and reliability of the saliency method in reality. Saliency outcomes of simulations of a construction should be compared with human assessments of visual integration as experienced in reality, after the construction has been built. Clearly, the quality of the simulation will play a very important role. Low quality simulations will generate lower correlation coefficients, which might not match reality. Developers should thus carefully design simulations which are as realistic as possible. While the effect of the simulations quality on the outcome of the saliency method should be investigated in greater detail, comparability problems will not arise as long as simulations of equal quality are compared. The method is intended for relative comparison of scenarios, not absolute predictions of visual impact.

A third issue that necessitates further investigation is the question whether only a neutral scenario should be simulated and tested. Weather and seasonal conditions will, for example, have a great deal of influence on the visual impact of a construction (Fabrizio and Garnero, 2012). Weather will influence the visibility as illumination conditions may vary. In sunny conditions, buildings are more likely to catch the attention by reflecting sunlight while in cloudy situations (or fog as a more extreme example) a building might be less striking because of reduced visibility. Similarly, season will impact on the visibility of a construction as it leads to ephemeral landscape features such as differences in crops, crop height, foliage density, colours of the vegetation etc. (Brassley, 1998). These aspects might have a considerable effect on the visual impact of constructions as in summer the vegetation might have a 'camouflaging' effect which disappears in winter. If the viewing pattern differs depending on the weather and season, these effects should be taken into account when calculating the visual impact of a construction. The aim is to achieve a kind of 'overall all-year visual impact'. This could be achieved by creating simulations for the different seasons and their accompanying weather conditions, considering the different conditions of the surrounding vegetation. However, as put forward by Brassley (1998), how many times would an assessment need to be performed before all ephemeral factors, which change with changing season and weather conditions, would be taken into account? This is far from being a simple task as a number of uncertainties arise which are different for each landscape. Crop choice might vary from one year to another, weather conditions might not follow the mean trend of the past decennia, surrounding vegetation may change by human or natural interventions etc. Furthermore, it is difficult to estimate how many days a certain scenario will be applicable in practice. One possibility is to make one scenario per season, reflecting the most common weather conditions for that season, and multiply the corresponding visual impact (saliency correlation coefficient) by 91 (approximate length of a season in temperate regions). The addition of the calculated impacts for the four seasons would then generate an 'overall all-year visual impact'. This might seem simplistic but it is almost impossible to include all variable weather and seasonal aspects into this calculation. As we are interested in long-term visual effects, visual impact calculations should take into account long term weather statistics, crop choice statistics and temporal information about foliage development and leaf fall in order to determine the 'overall all-year visual impact' as accurately as possible.

Related to this issue is the fact that generally the visual impact, as will be experienced from one specific viewpoint – usually the worst case viewpoint – is considered while the visual integration might be significantly different from other points of view. As a consequence, it is recommended to estimate the visual impact from multiple viewpoints in order to obtain a more complete idea of the impact. Again, it is not possible to assess the visual impact for the entire 360° around a construction. Instead, it would be more relevant to select the viewpoints according to specific criteria important in determining the visual impact. Simulations should, for example, be made from viewpoints from which the construction will actually be seen by people such as roads and paths, taking into account traffic density; from viewpoints from which landscape perception should be preserved (Wu et al., 2006; Fabrizio and Garnero, 2012); from viewpoints familiar to inhabitants; from strategic viewpoints (e.g. lookout points for tourists) (Bouchard and Boudart, 2005) etc.

Finally, further research is necessary to determine whether the saliency method could be valid in other types of landscapes than the rural landscapes tested in this study. This is important as the characteristics of the landscape are considered to determine a landscape's 'visual absorption capacity' in receiving new elements (Smardon et al., 1986; Rodríguez and Martín, 2011; Curado and Marques, 2012). These characteristics comprise the degree of urbanisation, topography, vegetation cover, degree of openness etc. (Curado and Marques, 2012). Greenhouses or electrical infrastructures, for example, are considered to be less disturbing in industrial landscapes than in residential or rural areas (e.g. Rogge et al., 2008; Curado and Marques, 2012). Hernández et al. (2004) point to the importance of the openness of the landscape in determining the sharpness of the contrast of a construction against its background. This contrast, and thus the visual impact, might differ enormously when the background consists of sky (in open landscapes) or land (in enclosed landscapes). In open landscapes, constructions are more prone to interrupt the horizon and to be visible from many different viewpoints, increasing their visual impact, whereas in enclosed landscapes constructions can be more easily 'absorbed' by the surrounding land (Hernández et al., 2004). In a more urban environment, the visual absorption capacity is expected to be higher since earlier research has found very scattered viewing patterns occurring in these landscapes (Dupont et al., 2016b). As a consequence, people's attention could easily be derived from new constructions because there are a lot of other things to look at in these landscapes. In addition, the number of viewpoints will also be restricted because of the more dense building structure in a city, limiting the potential views on a construction.

6.5 CONCLUSIONS

The saliency-based method for visual assessment based on photographic landscape simulations as proposed by Dupont et al. (2016a) has been demonstrated to be useful and reliable for evaluating the visual impact of remote constructions in the rural landscape. The method is able to discriminate between scenario simulations of different colour and size of the object. Moreover, the results are consistent with human assessments of visual impact in that the same scenario simulations are indicated as being visually most integrated. For differences in design, this was not the case, indicating that the visual aspect – although dominant – is not the only factor which is taken into consideration when choosing a design.

We believe that the proposed method allows an objective visual impact assessment, which can help in deciding between scenarios of a construction without being deterministic. The method is fast and easy to perform and has been demonstrated to be a reliable proxy of human assessments of the visual integration of a construction in terms of colour and size. Slow and expensive public consultation rounds can thus be minimized in the early design stages. The fast procedure allows to assess many different simulations and to test the visual impact of a construction from many different points of view. This is a huge asset as it offers very detailed and complete information of a construction's visual assessment. It can also be applied in the very early stages of the planning process, i.e. in the design stage, which is crucial as in later stages (e.g. construction phase), visual impact reducing or enhancing adjustments are far more difficult to accomplish.

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PART IV

GENERAL DISCUSSION AND CONCLUSIONS

CHAPTER 7: GENERAL DISCUSSION

This general discussion starts with a summary of the main results obtained throughout this dissertation. Table 7.1 provides an overview of the findings and their interpretation listed per research question. Subsequently, we discuss how these results contribute to landscape research in general (section 7.1) and how they relate to the broader theoretical background of environmental perception (section 7.2). The implications for landscape planning and design are described as well (section 7.3). Furthermore, we provide a critical reflection on the constraints which are inherently connected to eye-tracking experiments (section 7.4). These are two-fold: (1) constraints of using a table-mounted eye-tracker and (2) limitations caused by the experimental design of the experiments. In section 7.4.1, we discuss the first type of constraints in detail and argue how these can also offer advantages. In addition, the advantages and disadvantages of using head-mounted eye-tracking instead of table-mounted eye-tracking is discussed as well as the reasons why this method was not used in our study. Section 7.4.2 deals with the restrictions caused by the design of the experiments. In section 7.4.3 a critical reflection on the statistical tests used to study the eye-tracking metrics is provided. Finally, this chapter is concluded with opportunities for follow-up research (section 7.5). Ideas arising from the shortcomings identified throughout our experiments (section 7.5.1) and further research concerning the saliency-based method for visual impact assessment are presented (section 7.5.2).

Table 7.1 Overview of the dissertation's main results and corresponding interpretations per research question and objective.

Research question	Research objectives	Chapter	Methods	Main results	Interpretation
RQ 1: Practical context	RO 1: Investigating if and how the view angles of the photographs influence the viewing pattern in landscape photographs.	2	- Landscape photographs - ETM - Statistical testing	- Panoramic photograph is observed differently than standard photograph: more fixations and saccades, shorter fixations, larger and faster saccades	- More extensive exploration and easier information extraction in panoramic photographs - Landscape presented by panoramic photograph might be easier to recognise and memorise
RQ 2: Landscape characteristics	RO 2a: Examining the effect of the degree of openness of the landscape on the viewing pattern. RO 2b: Analysing the influence of the degree of heterogeneity of the landscape on the observation behaviour. RO 2c: Investigating how the observation of landscape photographs is influenced by the level of urbanization of the landscape. RO 2d: Determining if differences in viewing behaviour elicited by the degree of urbanization are related to differences in the visual complexity of the landscape photographs.	2 + 3	- Landscape photographs - Sorting task - ETM - Statistical testing - Correlation analysis	- Open landscapes: less fixations and saccades, longer fixations, faster saccades - Homogeneous landscapes: longer saccades, larger observed vertical area, larger Voronoi cells - Increase in urbanisation leads to increase in fixations, saccades, scan path length and Voronoi cell area (rural landscapes do not follow this trend) - Level of urbanisation is positively correlated with visual landscape complexity: results found for urbanisation level also apply to visual landscape complexity	- Less extensive exploration and hampered information extraction in open landscapes - More extensive exploration in homogeneous landscapes - Visual exploration increases when level of urbanisation/visual landscape complexity increases - Rural landscapes do not follow this trend and elicit stronger visual exploration than expected - Buildings determine to viewing pattern to a large extent
RQ 3: Observer characteristics	RO 3a: Investigating if and how landscape-related expertise affects landscape observation. RO 3b: Determining on which type of features in the landscape experts and laymen spend most attention.	4	- Landscape photographs - ETM - AOI - Statistical testing	- Expertise leads to more fixations and saccades, shorter fixations, longer scan path, larger Voronoi cells - Both groups spend most attention to buildings but non-experts fixate more and longer on buildings than experts	- Expertise: more efficient information extraction → more time for visual exploration → larger visual span - Buildings are structuring elements determining the viewing pattern, this is more true for non-experts than for experts

RQ 4: Application in landscape planning and design	RO 4a: Analysing if saliency maps can be used as reliable predictions of the human viewing pattern in landscape photographs. RO 4b: Determining if saliency based visual impact assessment can be a valuable method for evaluating the visual integration of new construction in the landscape.	5 + 6	- Eye-tracking focus maps - Landscape simulations - Saliency maps - Photo-questionnaire - Statistical testing - Correlation analysis	- Positive correlation between saliency maps and human focus maps - Correlation decreases with increasing urbanisation - Saliency based method for VIA discriminates between scenarios differing in colour and size - Positive correlation between VIA results based on saliency maps and VIA results based on human ratings	- Saliency maps are reliable predictions of the human viewing pattern - Viewing pattern is better predictable in rural landscape with limited urbanisation - Saliency map comparison can be considered as a useful helping tool for VIA in landscape planning and design

7.1 PRACTICAL IMPLICATIONS FOR LANDSCAPE PERCEPTION RESEARCH IN GENERAL

The results of this study allow to formulate suggestions and recommendations for further research on visual landscape perception. In particular, these relate to the use of landscape photographs presented in Chapter 2 (research question 1). Exploration patterns in panoramic photographs proved to be different from other photograph types (Table 7.1). This is consistent with earlier research which indicated panoramic photographs to elicit different responses (Nassauer, 1983; Sevenant and Antrop, 2011). Our study demonstrates that panoramic landscape representations elicit more extensive visual explorations. The viewing patterns in panoramic photographs suggest an easier information extraction and probably a faster understanding. Recognition and memorisation are therefore expected to be facilitated. This is relevant for landscape perception studies using photographs, although it still remains to be confirmed by more detailed further investigation. The choice of photograph type concerns two aspects: a difference in viewing pattern and a difference in the cognitive processing of the photograph.

The first aspect is particularly important in studies which focus on visual aspects of the landscapes. Visual impact assessment studies might, for example, lead to different outcomes when performed based on standard or panoramic photographs. As panoramic photographs contain more landscape elements, the visual impact of an object as experienced in a standard photograph might be less dominant in a panoramic photograph since attention might be turned to something else which was not present in the initial standard photograph. According to Nassauer (1983), panoramic photographs provide a greater amount of information and allow the observer to scan a broader view of the landscape, which results in more valid responses or judgements.

The second aspect is relevant for research which necessitates making interpretations of the landscape or which involve memorisation tasks. Examples include questionnaires which are based on photographs or reproduction tasks which require memorisation of the landscape (e.g. when people are questioned *after* having seen landscape photographs). Such tasks are expected to be easier when panoramic landscape photographs are used. The most probable explanation is that panoramic photographs provide a more complete view on the landscape and more approximate the binocular human field of view, which comes closer to the real landscape (experience) (Zube et al., 1974; Nassauer, 1983; Palmer and Hoffman, 2001). When people have more information at hand, they are able to figure out more about the landscape as a whole and better estimate the broader context. Navon (1977) argues that this facilitates interpretation as features are easier to recognize and to understand within the appropriate context. When performing landscape perception studies, we recommend to consider this information and to choose the type of photograph which is most suitable for the objective. More important, we want to stress potential comparability issues when both standard and panoramic photographs are mixed and thus recommend to choose one of the two options.

7.2 CONTRIBUTION TO THEORIES OF LANDSCAPE PERCEPTION AND EXPERIENCE

The answers provided on research question 2 (Chapter 2 and 3) which relate to the landscape character, can be placed in the broader context of landscape perception theories. Briefly summarized, the results show that landscapes are viewed differently depending on their character in terms of openness, heterogeneity and degree of urbanisation, related to visual complexity (Table 7.1). More open landscapes appear to elicit a weaker visual exploration probably as a result of the lack of large objects present in the foreground and middleground of the photograph. Instead, people seem to focus on the small objects situated in the background and on the horizon. The degree of urbanisation and the associated complexity seems to enhance the exploration because of the greater information content of the image (more colours, edges etc.). In Chapter 2, we concluded that the visual exploration of homogeneous landscapes is weaker than in heterogeneous landscapes. However, some caution is necessary as this conclusion is only based on the lower number of fixations (see Chapter 4, section 4.2.5.2). More reliable interpretations about the extent of the visual exploration can be made based on the observed vertical and horizontal area, or even better, based on Voronoi cell areas constructed around each single fixation point (see section 4.2.5.2). The larger observed vertical area found in homogeneous landscapes (see Table 2.4) indicates a more extensive visual exploration in this type of landscape. This is confirmed by an additional Voronoi cell area analysis performed on the fixations made in the homogeneous and heterogeneous landscapes (see Table 7.2). The Wilcoxon Signed Rank test reveals significantly larger Voronoi cells in homogeneous landscapes, which indicates more dispersed fixations and thus a more extensive visual exploration.

Table 7.2 Results of the Wilcoxon Signed Rank test for the Voronoi cell areas.

	N	Mean rank		P
		Homogeneous	**Heterogeneous**	
Voronoi cell area	8929	1.57	1.43	0.000

In consequence, we can conclude that, in contrast to what is described in Chapter 2, homogeneous landscapes appear to elicit a more extensive visual exploration compared to more heterogeneous landscapes. This conclusion might seem in contradiction with the conclusions drawn concerning the influence of the visual complexity of the landscape photographs. In Chapter 3 we demonstrated that visual landscape complexity, considered to be a highly similar measure to landscape heterogeneity (see section 1.5.2), seems to enhance the visual exploration. However, in that study, rural landscapes lacking any buildings did not follow this trend and generated a stronger visual exploration than would be expected based on the low visual complexity of the landscape photographs. This explains the apparent contradictory results found for the homogeneous-heterogeneous landscape categories. The homogeneous landscapes investigated in Chapter 2 predominantly consisted of landscapes which match the rural landscape category analysed in Chapter 3. In addition, the landscapes classified as heterogeneous are comparable to the semi-rural and mixed landscape categories. Consequently, the more extensive visual exploration of the homogeneous landscapes is consistent with the results obtained for rural landscapes and the weaker visual exploration in heterogeneous landscapes matches the results found for semi-rural and mixed landscapes characterised by a limited visual exploration. We can conclude that the visual exploration behaviour in landscapes differing in heterogeneity and complexity are consistent. In particular, heterogeneity and complexity increase the visual exploration behaviour. Therefore, we will treat heterogeneity and complexity as substitutes of each other. Homogeneous rural landscapes do not follow this trend and elicit unexpectedly strong visual exploration patterns despite their low visual complexity. These results are consistent with earlier research where indications of different viewing behaviour depending on the degree of complexity of a scene were found (e.g. Buswell, 1935; Berlyne, 1963; Wohlwill, 1968; Mackworth and Morandi, 1967). Furthermore, the results contribute to the theoretical framework for analysing visual landscape character as set up by Tveit et al., (2006) and Ode et al. (2008). For the variables openness and heterogeneity/complexity tested in our study, a clear difference in viewing behaviour was found when these landscape aspects varied. This confirms the variables' validity for visual landscape classifications. The significant differences in viewing patterns indicate that people indeed react differently according to these properties of the landscape.

Our study also identified buildings to act as eye-catchers which considerably determine the viewing behaviour. Clear differences in visual exploration were found in landscapes varying in degree of urbanisation. In particular, the presence of isolated buildings in a rural environment strongly restricts the visual exploration (centred around the buildings) while for increasing levels of urbanisation, the viewing pattern gradually becomes more scattered (Table 7.1). These results seem in contradiction with the conclusions of the study by Berto et al. (2008). This study investigates differences in viewing behaviour between highly restorative environments and weakly restorative landscapes, which appear to be natural and built environments respectively. More fixations and a longer covered distance (scan path) were found in the urban images while the opposite occurs in natural scenes. This suggests a more extensive visual exploration of urban scenes compared to natural scenes, while our study indicates a strong visual exploration in both types of landscape and a weaker exploration in the intermediate types (limited amount of buildings in rural environment) (Table 7.1). However, this difference might be due to the fact that the natural landscapes in the study of Berto et al. (2008) do not correspond to our 'rural landscapes'. In particular, Berto et al. (2008) initially provided the participants with a number of photographs representing natural, built and mixed environments and asked them to evaluate their restorativeness. Only the 25 photographs with the highest scores and the 25 images with the lowest scores were included in the study, the other scenes were eliminated. The top 25 images with the highest scores seem to consist of mostly natural environments, while the other group are mainly built scenes. However, it is not clear from the article whether the 25 natural landscapes are indeed completely natural and thus do not contain any buildings. In other words, were the mixed scenes all deleted? If not – and the example image provided in the article seems to confirm this as the natural image contains a small cottage – this would explain the deviating results. Then, the natural images could, at least partially, be similar to our 'semi-rural' landscape category, in which indeed restricted viewing patterns with less fixations and less visual exploration were found.

The finding that buildings, because of their eye-catching power, have a great influence on the viewing behaviour in landscape photographs, can be related to different theories of landscape perception for different reasons. A first theory which very likely plays a role in explaining this result is the Gestalt theory (Köhler, 1947). As buildings consist of different materials, colours and shapes which differ from the natural landscape, a number of Gestalt principles might cause people to focus attention on them. In particular, sharp edges of buildings highly contrast with the background and are therefore detected. Gestalt principles which come into play in this situation are the figure-ground principle and the principle of continuity. As landscapes are mainly scanned in a horizontal direction (Nassauer, 1983), sharp vertical edges caused by buildings break the continuity, causing more focus on these edges. The specific and well-delineated shapes of a building also activate the figure-ground principle which differentiates the building from its background. This detection is very likely to elicit greater attention spend on the 'figure'.

The eye-catching nature of buildings can also be placed in the light of evolutionary theories such as the Prospect-Refuge theory (Appleton, 1975, 1988), the Savannah-theory (Orians, 1986) and the Information-Processing theory (Kaplan and Kaplan, 1995). While our ancestors perceived the environment in terms of prospects (places offering an overview on the landscape) and refuges (places which offer shelter) in order to maximize survival, it is probable that this pattern through evolution and natural selection became instinctive and innate. An extreme example of this is the reflex to run away and hide or find a safe place which offers an overview of the situation in acute danger, when people's self-control is overruled by the instinct (Quarantelli, 1954). A more common example is the way in which people choose a place to rest during a walk, a place to have a picnic or even a table on a terrace to have a drink. The spot chosen will almost always provide prospect and refuge at the same time. Benches along walking trails, for example, are generally not placed in the open field but instead are situated under a tree or in front of a hedgerow. Picnic places are not chosen in plain sight but rather somewhat hidden, in a place which offers a kind of safe 'cosiness' and which at the same time provides (broad) views on the surroundings. The same happens when people are asked to choose a table for a drink on an empty terrace. Tables in the middle of the terrace are rarely picked out. Instead, people seem to prefer a place at the edge or in a corner of the terrace, close to the façade of the pub. Again, this choice reflects the search for shelter and prospect (Hildebrand, 1999; Blake, 2015). Unconsciously, people thus scan their environment according to Appleton's theory of prospect and refuge and prefer settings in which both are provided (see Savannah-theory of Orians (1986)). Our results provide tentative evidence confirming these theories. As described in Chapter 4 (section 4.4.2), the fact that human attention is attracted to buildings could be ascribed to the evolutionary development of human viewing behaviour which unconsciously is always in search of refuges which offer prospects and which is still persisting in modern humans. As buildings can be considered as a modern form of refuge from which prospect is possible, they might catch the attention and determine the viewing behaviour. However, these conclusions are very tentative. From our studies, we cannot draw well-founded conclusions since the experiments were not set up with the specific purpose of empirically testing the Prospect-refuge and Savannah-theory. While these theories are widely accepted, they have never been empirically tested. We believe that this should be subject to further research. As demonstrated in this dissertation, eye-tracking in combination with thinking aloud could be a very useful and fast technique for achieving this.

The Information-Processing theory of Kaplan and Kaplan (1995) has been empirically tested on its predictive capacity concerning landscape preference (Kaplan, 1973). However, if and how this theory is reflected in the human visual behaviour has not been studied yet. The influence of the four informational factors, complexity, coherence, legibility and mystery, on the viewing pattern in landscapes can be examined using eye-tracking. The effect of the degree of complexity on the visual exploration has already been tested in Chapter 3 of this dissertation. Coherence and legibility, which have not been tested yet, are both related to the understanding of a landscape. More specifically, greater coherence and legibility are expected to enhance understanding (Kaplan and Kaplan, 1995). This can be tested in an eye-tracking study by letting participants view a number of photographs of landscapes differing in degree of coherence (level of order and unity; quantified) and legibility (ease with which one can orient himself in the landscape). Both variables should then be quantified or assessed in advance of the eye-tracking study. Participants should be asked to encode and remember the landscape as detailed as possible and draw the landscape on a blanc paper while speaking out loud their thoughts (thinking aloud). This procedure allows to discover (1) how these landscapes are visually observed and (2) how easily they can be remembered and recalled depending on their level of coherence and legibility. Mystery should be tested using mobile eye-tracking. As mystery involves the promise to learn more about a site/place/landscape when one has the opportunity to move further into the landscape, participants should be given this opportunity. The route chosen by the participant and the eye movements occurring when moving through the landscape can then reveal whether or not landscapes with higher mystery levels indeed generate a greater visual exploration as put forward by the theory of Kaplan and Kaplan (1995).

The results dealing with the degree of urbanisation of a landscape presented in Chapter 3 can be related to the affective response model formulated by Ulrich (1983). In particular, the deviating results found in 'rural landscapes', which seem to be visually explored more extensively than would be expected based on their low level of complexity (Table 7.1), were explained by the fact that participants got bored and started to search for interesting elements or made up their own time-filling task since the scenes did not have much to offer (see section 3.5.2). Reasons for this visual behaviour might also be found in the affective state of the observer towards natural scenes. According to Ulrich (1983), an affective response of preference to a scene stimulates an impulse of exploration behaviour, including enhanced visual exploration and information processing (Ulrich, 1983). Several studies have demonstrated that even unspectacular natural environments are preferred over built scenes (Kaplan et al., 1972; Zube et al., 1975; Wohlwill, 1976; Palmer, 1978; Ulrich, 1981; Ulrich, 1983; Ulrich, 1986). In addition, this preference seems to be irrespective of the properties of the landscape (e.g. complexity) but rather appears to be the result of people responding in a fundamentally different way to natural landscapes compared to built environments. Furthermore, scenes eliciting this kind of response are not restricted to wilderness but also include man-made structures such as crop fields, wooded parks etc., as long as no buildings or other built features are present (Ulrich, 1983). The photographs classified as 'rural' in our experiment meet these properties. As a consequence, the deviating results found for these landscape category could be explained by Ulrich's theory of affective response (1983). It is possible that the rural images were preferred over the other scenes eliciting an affect of interest and pleasantness, leading to an increased will to (visually) explore the landscape. This has potentially been reflected in the increased visual exploration of the rural photographs. The stronger visual exploration in the rural landscape category could thus be caused by the affective state of the observer, which could overrule effects of complexity etc.

Further research is required to find evidence to confirm this hypothesis. The very initial response to a landscape photograph should be measured, for example by only displaying the image very briefly (for some tenths of a second) in order to suppress cognitive responses and probe participants’ affective reaction.

7.3 IMPLICATIONS FOR LANDSCAPE PLANNING AND DESIGN

The fact that landscape characteristics such as openness and complexity influence the viewing behaviour is relevant in a planning and design context because it indicates that landscape changes and development projects could have a very different visual impact depending on the type of landscape in which they are executed. For example, new constructions are expected to catch less attention in more complex landscape sceneries which already contain a lot of information and thus in which there are other things to look at. Constructions in simpler, homogeneous landscapes are more likely to cause a large visual impact as isolated buildings in a rural environment have been demonstrated to act as eye-catchers and to highly determine the viewing pattern (see Chapter 3). The same reasoning applies to open landscapes, in which the attention is mainly focused on the background. When inserting a building in the foreground or middleground, it is likely to catch the attention and thus increase the visual impact whereas in more enclosed landscapes the objects already present in the fore- and middleground cause a more equally spread attention deployment, which is expected to distract attention from the new construction. This is important information to take into account when locations for new projects are to be decided.

The results discussed in Chapter 4 are relevant for the visual component of landscape planning and design in the sense that they confirm the effect of expertise on landscape perception. Lay people seem to observe the same landscape differently from landscape experts such as landscape architects and planners, landscape ecologists and landscape researchers (Table 7.1). This empirical evidence is important to take into account when considering the views and judgements of different actors and points to the necessity of consulting different stakeholder groups as stimulated by the European Landscape

Convention (Council of Europe, 2000). As Kaplan (1988) states, expertise is invaluable when used properly but experts are a dubious source of objective judgement with respect to what people are concerned with in the landscape. In this context, our findings clearly point out that public involvement is highly required and essential since experts' view indeed cannot simply be considered as representative of the general public's view (which is also clear from the often diverging assessments of landscapes obtained from both groups (Kaplan, 1973; Anderson, 1978; Godschalk and Paterson, 1999; Bell, 2001; Sevenant, 2010; Howard, 2013)). Landscape design processes which do not include public participation are based on expert judgement, which is based on different visual information than would be obtained by the public. It is thus likely that choices made based on this substantially different way of observing the landscape might not match the public's choice. However, it is the public who are most confronted with the landscape and who are most concerned with its management and change as it affects their quality of life and shapes their regional and local identity (Scott, 2002; Hall et al., 2004; Scott and Moore-Colyer, 2005; De Groot, 2006; Vouligny et al., 2009). As a consequence, their concern should be taken into account.

However, public participation is often difficult to organise, time-consuming and inefficient. In Part III we have presented a method, the saliency approach to visual impact assessment, which could facilitate certain parts of this process. As saliency maps reflect the viewing pattern of most people (Table 7.1) (with exception of landscape experts), they could be used to estimate the visual impact of new construction as would be seen by the public. This saves time as it is more efficient than probing public opinion. It should, however, clearly be stressed that the saliency method is only useful for assessing the visual component of landscape change and thus can only be a substitute for the visual assessment part of the planning process. While this is an important aspect, it is not the only one. We believe that when it comes to a project's functionality, accessibility (potential mobility issues), financial cost, ecological cost (pollution) etc., consultation of the public should be considered as indispensable.

Obviously, the eye-tracking technique has proven its usefulness, effectiveness and reliability for use in academic landscape perception research. This encompasses fundamental research on principles of landscape perception, guiding mechanisms, influencing factors etc. However, its practical use is very unlikely because of a number of very substantial, if not insuperable, limitations which are difficult to match with the everyday practice of landscape planning and design. Eye-tracking is a time-consuming technique for several reasons. It requires sufficient participants to form a representative sample of the public, which is not always easy to achieve and which can be costly. In addition, the data gathering (performing the experiments), data processing and data analysis are long and complicated processes which can take several months. This requires a certain level of expertise which also takes years to acquire. Finally, an eye-tracking device together with the accompanying software package is a very expensive equipment which costs up to several ten thousands of euros. All these aspects strongly impede a widespread use of eye-tracking in practice. Therefore, derived products, which are based on information obtained through eye-tracking or which have been tested and validated by eye-tracking and which are much cheaper, faster, more efficient and more user-friendly, have far more potential to be used in practice. An example is provided by the saliency method for visual impact assessment as presented in Part III. Eye-tracking itself is much more suitable for conducting studies which contribute to the theoretical framework of landscape perception, generating useful knowledge for practical applications.

7.4 CRITICAL REFLECTIONS ON THE EYE-TRACKING METHOD

7.4.1 Constraints and advantages of using table-mounted eye-tracking

7.4.1.1 Use of photographs and its implications

Research concerning the visual aspect of the landscape can be performed either on-site, in the real landscape, or off-site, using visual representations of the landscape (e.g. landscape photographs or simulations). Respondents are then usually asked to assess specific elements of the landscape or the entire appearance of the landscape. In on-site situations, this often involves completing a questionnaire while experiencing and looking at the landscape (e.g. Bishop and Rohrmann, 2003; Chhetri et al., 2004; Sevenant, 2010). In off-site situations, respondents observe the landscape indirectly on photographs (photo-questionnaire) (e.g. Scott, 2003; Ryan, 2006; Sevenant, 2010). For the experiments in this dissertation, a table-mounted eye-tracker was used since the aim is to investigate the observation of landscape photographs. The use of photographs requires a non-portable the eye-tracking device, which entails a number of limitations but also provides some advantages.

First of all, while the validity of photographs as substitutes for real landscapes has been acknowledged (e.g. Shafer and Richards, 1974; Daniel and Boster, 1976; Zube, 1974; Shuttleworth, 1980; Coeterier, 1983; Zube et al., 1987; Sheppard, 1989; Palmer and Hoffman, 2001), a photograph might not elicit the same experience as the in situ experience. In this regard, Berto et al. (2008) point out that the viewing pattern in landscape photographs might not be completely equal to the viewing behaviour in the real world. In the real landscape, people's perception is not only determined by the eyes but also by head movements, which makes human vision an active and dynamic process based on interaction between the observer and the environment (Hilgard, 1982; Henderson et al., 2003). The eye-tracker used in our first experiment (Eye Link 1000 from SR Research) was equipped with a forehead and chin rest, which did not allow any movements of the head. The eye-tracker used in the other experiments (RED250 eye-tracker from SMI) did not use these attributes and the participants received more freedom concerning head movements. However, totally free movements including large rotations of the head were not allowed in order to avoid losing track of the eyes. Such limitations could have impacted on the results. While, because of the validity of photographs as surrogates of the real landscape, we assume that tracking results for photographs are similar to tracking results in the real world, there is no direct evidence for this.

Second, the use of photographs deprived the experiments of all types of movement. The participants were inhibited from moving through the landscape and moving elements in the landscape could not be represented by static photographs. However, landscape is a three-dimensional space in which people are used to move and see movement. A considerable part of how an individual experiences and looks at the landscape will thus be influenced by this third dimension. As a consequence, any two-dimensional picture plane representations of the landscape will miss a lot of what landscapes have to offer (Kaplan, 1988), which might influence landscape experience. For example, the use of photographs implies that images are pre-selected by the researcher, showing only one view on the landscape (Scott et al., 2009). The location from where the photograph is taken and the photographic conditions are decided by the researcher, and thus one very specific view on the landscape is provided (Nassauer, 1983). In the real world, however, the landscape can be experienced more fully and from whatever viewpoint one wishes to choose when moving through the landscape (Bell, 2001). Especially the location of the viewpoint controls the appearance of the landscape (Unwin, 1975; Nijhuis et al., 2011). Viewpoints from a more elevated location usually allow wider views while lower locations are more probable to restrict or close the view. The viewpoint also determines the number of depth plans. An elevated position generates views mostly dominated by the background while views obtained from a lower position are predominantly characterised by the foreground (Burton-Litton, 1968). Besides, moving through the landscape implies that elements which at first might not be visible may become visible when coming closer to the observer and vice versa. Objects which initially were already in the field of view may become more visible as they are seen at a larger scale and with more clarity when the distance to the observer decreases. This freedom cannot be reproduced when working with landscape photographs as the landscape in fact consists of an infinite amount of overlapping views providing a multiplicity of arrangements of the same features in foreground, middleground or background. Generating and testing such an amount of photographs would be a tremendous task (Unwin, 1975). In particular, introducing multiple views of the same landscape in an eye-tracking experiment would make the experiment too long, especially when testing more than one landscape. This might cause mental fatigue and discomfort for the participants. A possible solution is to use moving images of the landscape in combination with eye-tracking measurements (see section 7.4.2 for further details).

While photographs are always indirect substitutes for the real landscape, Kaplan (1988) states that for evolutionary reasons, people are highly qualified at perceiving depth and thus automatically interpret photographs of the environment in the third dimension. While this does not resolve the issues described above, it contributes to the validity of landscape photographs as surrogates for the real landscape.

7.4.1.2 Advantages of using photographs

For the reasons mentioned above, we should be cautious when extrapolating our results, found based on observations of landscape photographs, to observations made in the real landscape. However, the use of photographs also provides major advantages, especially for use in combination with eye-tracking, which would be hard to obtain when doing a similar study on-site. The most important benefit from using photographs is the possibility to control a number of variable factors, highly probable to influence the viewing pattern. Thus, landscape photographs can increase the level of standardisation. In each of our experiments, we were interested in analysing the effect of one or two factors on the viewing behaviour of the participants while keeping other factors constant as much as possible. Through the use of photographs, we were able to maximize standardisation of the following factors: weather conditions, season, presence of animals, humans and objects suggesting movement, view angle and camera height. While we suspect these transient aspects to have a considerable effect on the viewing pattern, we were mainly interested in testing the influence of specific factors on the viewing pattern rather than knowing the general viewing behaviour in landscapes with all its aspects and characteristics. Throughout all the experiments, the photographs were therefore taken in similar weather conditions, in the same season and in the absence of humans, animals or objects suggesting movement. In addition, the same camera height, view angles (except in the first experiment in which this specific photograph property was varied) and resolution were used to take all photographs so that the results were comparable across experiments.

As weather conditions, and especially the presence of white clouds in a blue sky, have been demonstrated to catch the attention because of sharp contrasts (Mackworth and Morandi, 1967; Itti, 2007), the photographs were all taken either with a clear blue sky, either with an even grey sky. However, in real life situations, the sky is an inherent part of the landscape and thus we should acknowledge that the viewing patterns made in our photographs cannot be entirely representative of real life conditions, especially when contrasting clouds or an intensively coloured sky is present.

Seasonal variations might also lead to different results. No landscape will look equal in all seasons. Mostly as a result of the vegetation, in particular, variations in foliage density, crop height and colours, called 'ephemera' in the landscape (Brassley, 1998), might have a great influence on the observation behaviour. Dense foliage and higher crops in the summer period might lead to more restricted views and more enclosed landscapes while in the other seasons more transparency is provided and thus broader views are possible. This is very likely to affect the viewing pattern and thus the eye-tracking results. Colours are even more probable to elicit differences in observation behaviour since colour has been demonstrated to have a major impact on attention distribution (Itti and Koch, 2000, 2001; Peters et al., 2005). In autumn, when the vegetation is characterised by a diverse colour palette, the attention might be more focused onto the vegetation compared to other seasons. In order to investigate landscape observation more thoroughly and completely, landscape photographs taken in all seasons, even over multiple years, should be included in the study (Granö, 1997). While this was not included in this dissertation, it offers possibilities for future research (see section 7.5).

A third factor which was kept constant is the absence of animals, humans and moving objects (e.g. cars) as these have been demonstrated to operate as real eye-catchers (Buswell, 1935; Yarbus, 1967; Thorpe et al., 1996). Photographs are the perfect medium in which such aspects can be easily removed using photo-editing software programs, which would not have been possible when performing the experiment in the real landscape. As such, the photographs provided the possibility to control or even rule out a great deal of aspects which would have been variable, and results incomparable, when performing the tests in situ. These advantages have been acknowledged by other authors as well (e.g. Sevenant, 2010). However, we should be conscious that this deprives landscape of one of its dimensions which is normally omnipresent.

7.4.1.3 An alternative method: head-mounted eye-tracking

A number of the constraints related to the use of a static eye-tracker, can be overcome when using a head-mounted eye-tracker. We refer to Table 7.3 for an overview of the advantages and disadvantages of table-mounted and head-mounted eye-tracking for the research presented in this dissertation. Mainly the fact that head-mounted eye-trackers offer the possibility to take the participants outside and perform the tests in the real landscape instead of based on a two-dimensional photograph, is a huge asset. A head-mounted eye-tracker, allows participants a lot more freedom in their movements. Since this type of eye-tracker is physically attached to the head of the observer, head rotations, which enlarge the field of view of the observer (Minelli et al., 2014), are allowed (Holmqvist et al., 2011). In addition, the participant can move through the landscape and observe the environment from self-chosen different viewpoints (Jacob and Karn, 2003). Moreover, a participant's choice of route and viewpoints can learn more about how the landscape is observed and which places and elements in the landscape are important or eye-catching, than would be possible based on landscape photographs. Finally, when using mobile eye-tracking, movement in the landscape originating from human activity (e.g. cars, boats etc.) or natural factors (e.g. wind effects, moving water etc.), which is an inherent part of the landscape, is automatically included in the experiment. All these aspects ensure that the landscape can be observed and experienced more fully (Bell, 2001).

Table 7.3 Overview of the advantages and disadvantages of table-mounted and head-mounted eye-tracking in landscape perception research.

Table-mounted eye-tracking	**Head-mounted eye-tracking**
Photographs	On-site
Restricted head movements	Free head movements
No movement through the landscape possible, one viewpoint	Movement through the landscape possible, different viewpoints possible
Uniform conditions concerning weather, presence of animals, humans and moving objects	Variable conditions concerning weather, presence of animals, humans and moving objects
Higher accuracy measurements	Lower accuracy measurements
Fast data processing	Time consuming data processing
No inconvenience caused by the equipment	Burden of the backpack and head-mounted equipment
No stimulation of other senses	Stimulation of other senses

While head-mounted eye-trackers obviously provide considerable advantages mainly concerning the more complete and realistic experience of the landscape, this method also encounters a number of shortcomings.

First, the accuracy of the measurements is lower compared to registrations made by table-mounted eye-trackers. Especially, head-mounted eye-trackers are calibrated at only one distance. Accuracy problems arise for objects situated at distances closer or further than the calibration distance. This effect can be minimized by placing the targets for calibration at a distance at which the stimuli are expected during the experiment (Vansteenkiste, 2015). However, in landscape observation studies, this is problematic as distances to objects are highly diverse. Furthermore, the accuracy of the measurements is also affected since head-mounted eye-trackers usually record the data at lower sampling rates, which is especially problematic considering saccades. In addition, the tracking ratio (percentage of the time that the eyes are tracked (Holmqvist et al., 2011) is influenced by direct sunlight. As sunlight contains infrared light, this interferes with the infrared light sent out by the eye-tracker, leading to frequent loss of the tracking signal and thus to low tracking ratios (Holmqvist et al., 2011; Vansteenkiste, 2015). However, improvements on this issue are made as eye-tracking manufacturers are starting to integrate sunshades in the glasses to rule out direct sunlight and thus increase the tracking ratio. The tracking accuracy has also been demonstrated to drop over time. Frequently, after a while the position of the helmet, cap or glasses which contain(s) the eye-tracking device, changes relative to the eyes of the participant. The initial calibration conditions are then lost and tracking accuracy decreases (Holmqvist et al., 2011).

Second, the data processing of the measurements made using a head-mounted eye-tracker is very time-consuming since most of the work (fixation and saccade detection, AOI identification for each fixation etc.) needs to be done manually and frame-by-frame. Depending on the type of experiment and its duration, this encoding can take several days or weeks (Duchowski, 2007; Holmqvist et al., 2011; Vansteenkiste, 2015).

Third, head-mounted eye-trackers require a laptop in order to be operational. This is often put into a backpack which then needs to be carried by the participant during the experiment. Together with the helmet, cap or glasses this may be experienced as annoying or heavy. This discomfort might lead to impediment of the moving behaviour and influencing of the viewing behaviour (Jacob and Karn, 2003). As a solution, head-mounted eye-trackers using a wireless connection to a notebook or tablet are currently starting to develop.

Fourth, as explained earlier, aspects such as weather conditions and the presence of humans, animals, cars or any other moving element can be ruled out when using photographs. When using mobile eye-tracking and performing experiments in situ, this is not possible. As a consequence, the experiment will be different for each participant as conditions might not be equal, making comparison difficult (Holmqvist et al., 2011). Participants tested on different days might, for example, be exposed to different weather conditions, not only affecting tracking accuracy (overcast versus sunny)

(Holmqvist et al., 2011; Vansteenkiste, 2015) but also the viewing behaviour. Different illumination conditions obviously affect the visibility (e.g. bright sky versus fog) (García et al., 2006) and the number of features which are visible or more clearly visible in a landscape is very likely to influence the observation pattern. In addition, occasional factors such as animals or other people present in the landscape has a great deal of influence on participants' eye movements (Buswell, 1935; Yarbus, 1967; Thorpe et al., 1996). The same holds true for moving objects such as cars, trains, boats etc. While our everyday landscapes are difficult to imagine without these features, their eye-catching nature has already been investigated and confirmed (Abrams and Christ, 2003; Franconeri and Simons, 2003). When one thus wants to know how the substantial, basic landscape is observed, transient features involving movement should be avoided. However, in some landscapes this is almost impossible. Similarly, it is impossible to remove movement caused by wind (e.g. waving trees) or water (e.g. flowing river) as these aspects are of natural origin and cannot be controlled by people. Since movement has been demonstrated to largely affect eye movements (Abrams and Christ, 2003; Franconeri and Simons, 2003), substantial differences in viewing pattern might be found between participants tracked on different days with different conditions (e.g. windless versus windy day, presence of animals/humans in the landscape versus empty landscape, cars passing by versus empty road etc.) as a consequence, comparability between subjects might become very complex.

Another comparability problem arises as a consequence of the different videos of the environment that are recorded for each participant during the experiment and on which the eye movement data is superimposed afterwards. The video depends on where the participant looked at and how he/she moved through the landscape (e.g. slow or fast). One participant might have looked to the left after 10 second while another one might have looked to the right after 5 seconds. Objects might also have been viewed from different distances, influencing their size. For these reasons comparability across participants is complicated.

Finally, when performing eye-tracking experiments on-site, the other senses (e.g. smell, hearing etc.) will be stimulated as well. Especially noise might, consciously or unconsciously, distract the participant and considerably affect the viewing behaviour (Holmqvist et al., 2011). Again, these facets cannot be controlled by the experimenter and will therefore be variable for each participant. In laboratory circumstances, all these aspects can be controlled through the use of photographs and standard settings for noise and light conditions (Holmqvist et al., 2011). However, in this set-up the link with the on-site landscape is weaker.

A number of these shortcomings could be solved by using an eye-tracker that is linked to a virtual environment. An example is given by the Oculus Rift (SMI). This device makes it possible to design a virtual environment in which the participant is submerged. Recently, the manufacturers integrated eye-tracking technology in the Oculus Rift, enabling the researcher to record eye movements while the participant is experiencing the virtual reality. This technique offers a number of advantages compared to standard head-mounted eye-trackers including freedom of movement of the observer, possibility to control variable conditions (weather, presence of animals, humans and moving objects), possibility to control the stimulation of other senses, no backpack to carry etc. However, a virtual landscape might not elicit the same observation as the real landscape, especially when the virtual environment is not realistic enough. In addition, as with standard head-mounted eye-tracking, the measurements are based on videos determined by the movement of the participants. These videos remain difficult to compare since movements are different for each person.

7.4.2 Limitations due to the experimental design

Limitations due to the experimental design refer to the choices made when setting up the eye-tracking experiments. First, it is important to ensure that all participants receive the same instructions as differences in tasks have been demonstrated to highly affect eye movements (Buswell, 1935; Yarbus, 1967; Castelhano et al., 2009). In all our tests, the participants were asked to actively observe the landscape photographs but no specific task, such as a searching or memorization task, was given. In the experiments we wanted to reproduce natural viewing conditions for landscape observation, which mostly occur freely and without a clearly defined task in mind. However, it is possible that, in free-viewing conditions, participants started making up their own tasks and thus might have had a purpose in mind guiding their observation of the photographs. This issue can never be ruled out, unless a task is given. When interpreting the results one should keep in mind the possibility of task-self-creation, especially when outliers in the data are encountered. In order to reveal a self-made task, participants could be asked questions about how they handled and experienced the viewing task after the experiment was finished. However, in our experiments such questions were only asked to participants whose viewing behaviour showed outlying or atypical patterns. This way, one case of task-self-creation was detected, i.e. a participant who was systematically scanning the images from left to right and from top to bottom. In two other cases, the atypical viewing behaviour was due to fatigue or nervousness and thus not related to task-self-creation. To prevent self-made tasks as much as possible, clear guidelines and instructions (without giving a specific task), standardized for all participants, were given. Instructions with respect to the objectives and progress of the experiment have to be clear, otherwise participants might start wondering, possibly leading to self-made tasks. Similarly, participants should be given an idea of the purpose of the study to prevent them from speculating and guessing why they are asked to observe the photographs. Providing clarity about the assignment can avoid this since top-down cognitive processes substantially affect the viewing behaviour (Rajashekar et al., 2008).

Second, the photographs in all our experiments were displayed for a fixed amount of time. This allows a proper comparison but at the same time limits the study of the viewing behaviour. The results of our experiments refer to the first 10 or 15 seconds of viewing time and are only valid for this period. It is, however, possible that viewing patterns become more scattered or more concentrated when an image is seen for a longer period of time. The display times in our experiments were specifically set at 10-15 seconds in analogy to similar studies conducted by De Lucio et al. (1996) and Berto et al. (2008) in order to keep the length of the tests acceptable and still including sufficient photographs to achieve statistical significance. 10 to 15 seconds might seem short but in eye-tracking terms, these are quite long exposure times (some participants of the first experiment mentioned that 15 seconds was very long). Ode Sang et al. (2014) and Pihel et al. (2014, 2015), for example, used only 5-7 seconds viewing time in similar studies. Important is that it has been demonstrated that the gist of a stimulus is assimilated in the first few hundred milliseconds of exposure (Biederman et al., 1983; Thorpe et al., 1996; Potter et al., 2002). Several studies also found evidence of the first impression being formed in these very initial stages of the viewing time (e.g. Lindgaard et al., 2006; Willis and Todorov, 2006; Dahal, 2011) and of this first impression forming the basis of the judgement about the content of a stimulus (Evans et al., 2000). Furthermore, Willis and Todorov (2006) point out that increased viewing time is mainly used to increase confidence in the judgement. This is an important finding, especially for the relevance and validity of our eye-tracking results for landscape research. If an opinion is formed in the initial viewing time, investigating the viewing pattern occurring within these 10-15 seconds of exposure time is relevant and sufficient. Differences in viewing pattern found beyond this period are less relevant in explaining differences in judgement of experts and laymen, for example. We can summarize that increasing the viewing time of our experiments might have led to increased/decreased differences in the general viewing pattern elicited in different types of landscapes or made by different groups of people. However, for relevance towards the visual component of landscape planning and design, an exposure time of 10-15 seconds is long enough to allow drawing general conclusions as opinions are predominantly formed in the very initial observation phase.

Third, one way of increasing the validity of the stimuli as representations of the on-site landscape without the need to use a mobile eye-tracker, is to use movies instead of static photographs. Videos provide the advantage of more realistically representing the real landscape while at the same time offering the researcher the possibility to control factors such as moving objects, presence of people/animals, weather etc., which cannot be controlled when participants are taken on-site (head-mounted eye-tracking). However, we did not use movies as stimuli because of technical and practical constraints. The technical set-up and data processing is more complex and more time-consuming. Issues concerning the technical set-up include synchronization problems between the stimulus presentation program and the recording software of the eye-tracker. While poor synchronization can be disastrous to a study, this problem is often difficult to solve, especially when experiments include many stimuli (Holmqvist et al., 2011). Data processing issues are mainly related to the very labour-intensive frame-by-frame encoding of the fixations. Depending on the total number of frames of the movies and thus on the quality of the video, this might be very time-consuming (Duchowski, 2007; Holmqvist et al., 2011).

Fourth, our studies focus on Belgian landscapes and a few landscapes in northern France. The landscapes selected for the eye-tracking experiments can be classified as cultural landscapes with clear anthropogenic influences. No natural landscapes were included. Furthermore, the selected landscapes were all everyday ordinary landscapes. This type of landscape is well-known to the participants but not widely known or famous. No iconic, extraordinary or sublime landscapes, such as the ones on the UNESCO World Heritage List, were included. This choice limits the extrapolation and generalisation of the results obtained through the eye-tracking experiments in this dissertation to other geographic areas with different characteristics such as mountain landscapes, desert landscapes etc.

Finally, while the eye movements provide information about the viewing pattern, no information about the mental processes operating while viewing the photographs were measured. We cannot know what people were thinking while doing the test. However, this could have provided insight into how the participants felt, which difficulties they encountered, what they were wondering about, why they were fixating certain objects, what their opinion was about these objects, whether they recognized the landscape etc. While eye movements provide a lot of information (e.g. long fixations indicate difficulty in understanding the object (Fitts et al., 1950; Just and Carpenter, 1976; Goldberg and Kotval, 1998), many fixations on an object are representative for its importance or noticeability to the observer (Jacob and Karn, 2003; Poole and Ball, 2005) etc.), they are far from learning us everything about the thoughts of the participant.

7.4.3 Reflection on the statistical tests

Datasets yielded from eye-tracking experiments are often very complex as a result of the multitude of aspects involved, which are related to the stimuli, the participants and the experimental set-up. In addition, each of these aspects is characterized by a degree of uncertainty which can originate from effects caused by the use of the eye-tracking technique, the characteristics of the participants, the influence of specific aspects of the presented landscapes and the possible interaction between these. When trying to generalize results from eye-tracking studies, researchers will mostly resort to statistical analysis. However, given the complexity, the potential uncertainty of the datasets and the variety of statistical tests available, it is clear that there is not a 'one-and-only' solution to statistically analyse the data. Instead, we believe that – while keeping an eye on the specific assumptions required to allow performing a statistical test – it is possible to analyse eye-tracking data in different fashions. In our first experiment, for example, we performed Kruskal-Wallis and Mann-Whitney tests. However, these tests do not take into account the fact that the observations of one participants in different photographs might not be completely independent. For example, a person who does not make a lot of fixations for some reason (fatigue, laziness,…) will do this in all stimuli. While there might be a difference depending on which stimulus is seen, the amount of fixations of such a person will be low in all stimuli. This suggests that the viewing behaviour, despite the free-viewing condition, is to some extent driven by the participant's individual characteristics and not solely by the content of the stimulus. This makes sense, otherwise all people would generate completely identical viewing patterns in free-viewing tasks. However, such dependency of observations was not tested in our experiment and thus we cannot be sure of its presence. As a consequence, we did not consider this in our first experiment (Chapter 2). However, in this general discussion, we provide the results obtained based on the Friedman and Wilcoxon Signed Rank tests, which do take into account this possible dependency of observations. The results of these tests are given in Table 7.4, 7.5 and 7.6. These tables are the equivalents of Table 2.2, 2.3 and 2.4 respectively (see Chapter 2).

Table 7.4 Results equivalent to Table 2.2 but taking the dependency of the observations into account by performing a Friedman and Wilcoxon Signed Rank test.

Eye-tracking metric	N	Mean rank per photograph type					
		Panoramic	Standard	Zoom 1	Zoom 2	Wide angle	P
Number of fixations	23	4.78	2.30	2.74	2.83	2.35	0.000
Fixation duration	23	1.22	3.83	3.22	3.26	3.48	0.000
Number of saccades	23	4.78	2.35	2.74	2.83	2.30	0.000
Saccade amplitude	23	5.00	2.09	2.17	2.48	3.26	0.000
Saccade velocity	23	5.00	2.17	2.04	2.87	2.91	0.000
Observed horizontal area	23	5.00	2.70	2.48	1.91	2.91	0.000
Observed vertical area	23	2.04	2.87	3.09	3.78	3.22	0.005

Table 7.5 Results equivalent to Table 2.3 but taking the dependency of the observations into account by performing a Friedman and Wilcoxon Signed Rank test.

Eye-tracking metric	N	Mean rank		
		Interest area on panoramic photograph	Standard photograph	P
Number of fixations	23	1.91	1.09	0.000
Fixation duration	23	1.00	2.00	0.000

Table 7.6 Results equivalent to Table 2.2 but taking the dependency of the observations into account by performing a Friedman and Wilcoxon Signed Rank test.

Eye-tracking metric	N	Mean rank Openness			P	Mean rank Heterogeneity		P
		Open	Semi-open	Enclosed		Homogeneous	Heterogeneous	
Number of fixations	23	1.48	2.13	2.39	0.006	1.35	1.65	0.049
Fixation duration	23	2.57	1.78	1.65	0.004	1.40	1.35	0.330
Number of saccades	23	1.39	2.17	2.43	0.001	1.35	1.65	0.050
Saccade amplitude	23	2.17	1.70	2.13	0.004	2.00	1.00	0.000
Saccade velocity	23	2.35	1.65	2.00	0.015	1.83	1.17	0.003
Observed horizontal area	23	1.87	1.83	2.00	0.200	1.48	1.52	0.209
Observed vertical area	23	1.57	1.83	2.61	0.001	1.96	1.04	0.002

From these tables we can conclude that, apart from very small differences, the results obtained by the Friedman and Wilcoxon Signed Rank test confirm the earlier results found based on the Kruskal-Wallis and Mann-Whitney tests. This might suggest that the dependent nature of the observations is not substantial enough to affect the results of the tests. However, in the other experiments, Friedman and Wilcoxon Signed Rank tests were performed in order to avoid drawing incomplete or erroneous conclusions by considering potential dependency anyway.

7.5 OPPORTUNITIES FOR FOLLOW-UP RESEARCH

Since eye-tracking only started to be used in landscape perception research in recent years, a lot of interesting topics which can be studied using eye-tracking, are still unexplored. While we believe that the potential of eye-tracking research is broad, we will only discuss ideas for further research related to the results of our study.

7.5.1 Further research dealing with the shortcomings identified in our experiments

First, further research is needed on the significance of the fixed time limit for displaying the photographs during the eye-tracking experiment. As mentioned before, the effect of extending the viewing time is unexplored. One interesting idea is to let people choose when to move to the next photograph. This could provide more insight as to how entertaining, informative, attractive, interesting, complex, difficult or confusing an image is to look at. Besides this, analyses can be performed to investigate how the viewing pattern evolves over time. Viewing patterns of 15 seconds could, for example, be split into the first 5 seconds, next 5 seconds and last 5 seconds. These separate analyses could learn much about the exploration strategies which people follow when visually exploring landscape photographs. It is, for instance, possible that a landscape is first examined generally and that in later phases of the viewing time this pattern changes to a more thorough inspection of specific elements present in the landscape. In this case, the first part of the viewing time would be characterised by a higher number of scattered fixations with shorter durations and longer saccades, while the later part would consist of long fixations concentrated on specific areas and smaller saccades. Such an analysis could contribute to formulating guidelines for which exposure time to use for which kind of landscape perception study.

Second, eye-tracking experiments in landscape perception research could be extended by adding the thinking aloud method to the experimental set-up, as has been done in other eye-tracking research (e.g. Kaakinen and Hyönä, 2005; Bucher and Schumacher, 2006; Conati and Merten, 2007; Ooms et al., 2015). This method consists of asking the participants to “think out loud” and formulate their thoughts and what crosses their minds while doing the experiment. In our experiments this technique was not used and thus we could only draw conclusions based on the objective landscape observation in terms of eye movements. While certain types of eye movements have been demonstrated to be related with typical mental states (Henderson et al., 2013; Kardan et al., 2015), they do not offer complete insight into the reasons why certain viewing patterns are made. This issue can be resolved when recording participants’ speech simultaneously with their eye movements, as it is then possible to analyse what they were thinking when looking at particular areas or objects in a presented scene. This additional information is very valuable for gaining insight in how certain aspects of a landscape are interpreted or why particular elements are focused on. For example, a blue house in a row of white houses might catch the attention but solely based on eye movements it is difficult to know the reason for this. Applying thinking aloud could clarify this reason as, based on the participant's thoughts, it will probably become clear whether the blue house was focused on because of its attractiveness, ugliness, confusion, surprise or just because of its deviating colour. Thinking aloud could thus clarify people's opinion and interpretation of what they are looking at. Do they like what they see, is it difficult to interpret or does it create confusion? Speaking out loud while viewing landscape photographs could also reveal what the expectations of the observer are. Does what he/she sees correspond to what he/she was expecting or is the content of the scene surprising? The mood of the observer might also become clear from thinking aloud. Was the observer tired, bored, nervous, afraid or curious, relaxed and excited? All these aspects might help explain the viewing behaviour and the reasons behind it. In addition, thinking aloud could reveal whether the participant is familiar with the presented landscape or not as people tend to spontaneously react when they recognize familiar places. Potential effects of familiarity on the viewing pattern, which are likely since the influence of familiarity with a landscape has already been demonstrated to affect landscape (change) experience and evaluation in general (e.g. resident versus non-resident studies conducted by e.g. Höchtl et al., 2005; Hunziker et al., 2006; Soini et al., 2012), could thus be detected. A final issue that could be resolved by using thinking aloud is the detection of 'task-self-creation' in free-viewing experiments, which cannot be confirmed or denied when only the eye movements are registered. It is very probable that participants will tell what they are doing and why they are doing so, when asked to speak out loud during the whole experiment. However, when a task-self-creation happens completely unconsciously, for example as a result of expertise, thinking aloud might not be able to capture this phenomenon either, simply because the participant does not realize it himself and thus will not speak about it.

Third, more research should be conducted to investigate the influence of people's background on their visual perception of the landscape. In this dissertation, only the effect of expertise in landscape related topics was tested. However, much more factors determine a person's background, all of them potentially influencing landscape perception. Sevenant (2010) distinguishes socio-cultural and socio-demographic factors. Expertise, amongst ethnicity, former and actual living environment, political conviction, membership of an association all contribute to a person's socio-cultural background. Socio-demographic factors comprise age, gender, socio-economic status (education level, type of job) and income class. Finally, values, behaviours and attitudes also determine someone's background (Sevenant, 2010). While age (Spooner et al., 1980; Hutton et al., 1983) and gender (Pan et al., 2004; Lorigo et al., 2006, 2008) have been demonstrated to affect the viewing pattern tested in diverse situations, their influence on visual landscape perception has not been studied yet. The same holds true for the other socio-demographic and socio-cultural characteristics mentioned above. Some of these factors might play a role in visual landscape perception since a number of them have been demonstrated to influence landscape experience and preference in general. Different studies have pointed out that age (e.g. Strumse, 1996; Soliva et al., 2010; Zheng et al., 2011; Howley et al., 2012), gender (e.g. Strumse, 1996; Sevenant, 2010; Soliva et al., 2010; Howley et al., 2012), education level (e.g. Zheng et al., 2011), values, attitudes and behaviour towards the environment (e.g. Kaltenborn and Bjerke, 2002a; Sevenant, 2010; Howley, 2011; Howley et al., 2012), cultural background (e.g. Buijs et al., 2009), profession (e.g. Gehring, 2006; Rogge et al., 2007; Soliva et al., 2010), membership of an environmental NGO (e.g. Strumse, 1996; Gehring, 2006; Soliva et al., 2010; Zheng et al., 2011), living environment (e.g. Strumse, 1996; Howley, 2011; Zheng et al., 2011; Howley et al., 2012), expertise (e.g. Rogge et al., 2007) and social class (e.g. Howley et al., 2012) all to some extent have an influence on how people perceive, experience and evaluate the landscape. Of particular interest for further research is the influence of expertise/profession and values towards the environment (potentially reflected in the profession and possible engagement in an environmental association), as these aspects are important for landscape management and planning. Landscape planning, design and management are inter- and transdisciplinary processes, in which usually a lot of people with different professional backgrounds are involved (e.g. planners, agronomists, foresters, real estate developer, landscape architects, heritage consultants, risk assessors, soil specialists, mobility experts etc.). Each of these actors has a very specific kind of expertise all related to landscape but though of very diverse origin. Since usually collaboration is required to manage or plan the landscape of a specific place, these actors need to reach consensus. However, this is not always the case and sometimes conflicts arise, often because the different groups of actors have different views on the landscape or on how it should evolve. In this context, eye-tracking could learn much about the cause of such disagreements as it could reveal how different actors perceive the landscape and what matters to them. Pointing them to the fact that they literally perceive the landscape differently could help understanding each other's views and facilitate consensus. In our study, we investigated the influence of expertise on landscape perception patterns. However, this included a mixture of landscape experts, no difference was made based on the kind of expertise. Further research should investigate if and how different types of landscape expertise are reflected in the viewing pattern made in landscape photographs. This idea can be extended to the broader group of people involved in landscape planning and management than only professionals. Since public participation is more and more stimulated as it is the public who daily lives in and experiences the landscape (De Groot, 2006; Nassauer, 1997; Seddon, 1986; Vouligny et al., 2009), insight into how different stakeholder groups visually perceive the landscape – which elements they fixate and thus find important – can be helpful in understanding people's wishes and opinions. Frequently involved stakeholder groups include farmers, local residents, tourists etc. In specific cases (e.g. for local residents), it might be interesting to examine the effect of age, gender, education, cultural background and social class as well.

Fourth, weather and seasonality have been acknowledged to influence landscape experience and evaluation (Fines, 1968; Shafer et al., 1969; Brassley, 1998; van Mansvelt and Pedroli, 2003; Stephenson, 2008). Palang et al. (2007) introduced the term 'seasonal landscapes' and studied its effect on landscape experience. However, no study has been conducted yet to find out if and how the visual exploration of landscapes changes with changing weather conditions and seasons. Weather will, for instance, influence the visibility and brightness of objects, while season may lead to different vegetation densities or colours. These are all aspects which are suspected to have a significant impact on the attention distribution in landscapes. Objects which are eye-catching in summer (sunny weather) might not be so in winter (overcast conditions) or on the contrary, objects which are not eye-catching in summer when the vegetation is dense might become eye-catching in winter when the vegetation is leafless. This is of particular importance for visual impact assessment based on landscape photographs (see Chapter 5, section 5.4.4).

Finally, our study only investigates everyday ordinary Belgian (and French) landscapes and thus we are unsure whether the results can be extrapolated to other landscape types and geographic regions. A further step in analysing the generalizability of our results, is to select regions with similar but different landscapes situated in other geographic areas and determine whether the results obtained for these landscapes match our results. Besides, the influence of a number of landscape aspects on the viewing behaviour could be tested in greater detail. Effects on the viewing behaviour caused by relief (flat versus mountainous) and the presence of water (rivers, lakes, coast) in natural landscapes, for instance, have not been investigated yet. The same holds true for extraordinary landscapes of natural (e.g. Yellowstone landscape, Bolivian salt flat, Halong Bay in Vietnam, ice landscapes in Antarctica) and anthropogenic (e.g. landscape of the Great Wall in China, skyline of New York, rice fields in southeast Asia, Egyptian pyramids etc.) origin. Related to the latter example, research could be conducted to assess the influence of (built) heritage on the visual exploration of landscapes.

7.5.2 Further research concerning the saliency method for visual impact assessment

First, the influence of the quality of the scenario simulations on the saliency correlation should be determined. Badly integrated elements, for example when the edges of the new object are not smoothed, will be detected as contrasting by the saliency algorithm and be classified as salient, while the new object in se might not be contrasting at all. The same argument is valid for colours which have been set too bright for the general illumination conditions of the background photograph (e.g. inserting a shiny element in an overcast landscape). These aspects are only important when the absolute visual impact needs to be calculated. However, our method is intended to compare different scenarios of a construction and thus the relative visual impact matters. In this latter case, the quality of the simulations will not be of primary importance as long as all simulations that need to be compared are of the same quality. Furthermore, the saliency method should also be tested on simulations of different nature. In our study, we only considered simulations which are based on real landscape photographs that have been slightly edited by inserting new objects. However, completely virtual simulations are often produced as well, for example using Visual Nature Studio (e.g. Appleton and Lovett, 2003; Paar, 2006; Dockerty et al., 2005; Williams et al., 2011; Pihel et al., 2014). First, it should be investigated whether human observers display the same viewing pattern in virtual simulations as in real photographs. Pihel et al. (2014) found evidence which confirms this similarity, however, their test only included images of forests lacking buildings or man-made constructions. Second, as we did for landscape photographs in Chapter 5, the human focus maps should be compared to the saliency maps obtained for the visualisations in order to confirm the validity of saliency maps as predictions of the human viewing behaviour. If these requirements are met, we should test whether virtually rendered visualisations generate similar saliency correlation coefficients than simulations based on real photographs or whether they score systematically higher or lower. This should be cleared out, especially when a threshold value (see last paragraph of this section for a critical reflection upon this idea) for acceptance would be used to decide upon acceptance (see Chapter 5, section 5.4.4). However, it will not be a problem as long as simulations of the same type are compared (without using a threshold). Visualisations and photograph simulations should not be mixed and compared. The same holds true for the photograph type of the simulations. Since the type of photograph has been demonstrated to affect the viewing pattern (Dupont et al., 2014), only simulations of the same type (e.g. panoramic photographs only or standard photographs only) should be compared.

Second, the validity of the saliency method for visual impact assessment should be empirically tested in urban environments. However, these scenes are much more likely to contain more colour variations because of the omnipresence of man-made elements. This could have an impact on the saliency calculation as this method takes the surrounding pixels, and thus the surrounding colours, into account. If this surrounding contains many different colours, the saliency detection algorithm is less likely to detect new features as being salient when its colour is present somewhere in the close surroundings. While built environments might be assumed to have a larger 'visual absorbing capacity' – meaning that new buildings are less likely to really pop out – it could either be that the saliency method is be less performant in an urban context. This can only be clarified by empirical testing.

Finally, more research is required to investigate how the outcome of the saliency method for visual impact assessment is related to the degree of acceptance of a project. We know that the method is consistent with people's opinion about visual integration/disturbance. However, we do not know if this is also the case with people's final choices of scenario, i.e. if they would have been asked which scenario they would choose to be built instead of just being asked to assess the visual integration. While people tend to make judgements based on what they see more than on what they know (Bell, 2001), the choice between different scenarios will not only depend on its visual integration into the landscape. Other aspects might play a role as well. People's preferences will, for example, depend on the individual characteristics of a person, the functionality of the construction, the degree of involvement in, or familiarity with the site in question etc. If respondents of the photo-questionnaire would have been asked which scenario they preferred to be built, the results might not have been the same as the ones obtained via the saliency method. In order to test this, and thus to check to which degree the visual integration of a building contributes to its acceptance, the photo-questionnaire presented in Chapter 6 should be repeated, now asking the respondents which scenario they would choose to be built in reality. While we suspect that the visual characteristics of a project in relation to its surroundings play a major role in the final decision of an individual, it is possible that people might not choose the best integrated scenario, but instead opt for a more eye-catching scenario just because they like that more. In this context, it is important to make a distinction between people who live in the area (e.g. people who see the new project from their place of living) and people who live further away or do not have any relationship with the area as this aspect has been demonstrated to have an impact on landscape (change) assessment (e.g. Coeterier, 1996; Kaltenborn, and Bjerke, 2002b; Höchtl et al., 2005; Gehring, 2006; Hunziker et al., 2006; Frantál and Kunc, 2011; Soini et al., 2012). It is hypothesized that people who will be confronted with the new construction on a daily basis will choose the visually more integrated scenarios in order to preserve their landscape. People with little or no concern in the area might be more tempted to choose more eye-catching scenarios, which would not match the outcome as obtained from the saliency method. The main point that we want to make here is that we should be well aware of the fact that the saliency method should only be used to determine the visual impact of different scenarios, and that this result can be taken into account when making the final decision. As such, our method is not deterministic, but rather indicative about one specific aspect: the degree of visual integration into the surrounding landscape. In this context, it is also important to note that the intention and purpose with which a project is designed should be kept in mind. Is the purpose to create a new landmark in order to strengthen the identity of the landscape? Or is the intention to integrate or even hide the construction as much as possible to preserve the existing landscape? In both cases, visual integration is approached differently as in the first case it would not be beneficial while in the second it would be required. As such, depending on the situation, visual impact can either be positive or negative and sometimes the best integrated scenario will not contribute most to the visual quality of the landscape. This interpretation is exactly what the saliency method cannot (or not yet) offer. It only objectively calculates the level of visual integration and the interpretation should be done by the designers and planners, depending on the purpose of the project (mostly imposed by the policy-makers). For these reasons, we believe that it is very tricky to establish a threshold below which projects are rejected.

First, it is very difficult to set up such threshold: When is the visual impact large enough to refuse a scenario? Second, factors other than the degree of visual integration – while considered as very important, if not dominant – also play a role in deciding upon a scenario for a project. Finally, our saliency method is not intended to be deterministic but to help facilitating the decision-making process by giving information about one specific aspect, the visual integration, without being a go-no-go tool. Clearly, if acceptance of a scenario would turn out to be mainly based upon the visual characteristics of the project, this would provide our saliency method with a greater power. However, as mentioned before, this first requires further empirical research.

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CHAPTER 8: GENERAL CONCLUSIONS

The first three research questions addressed in the present work, dealt with three fundamental factors, which are expected to influence landscape observation on photographs: the properties of the photographs, the characteristics of the landscape and the characteristics of the observer. Our eye-tracking experiments point out that the *photograph properties*, in particular the view angles of the photographs, seem to influence the viewing pattern. A difference is found between panoramic photographs and the other photograph types (all standard size photographs but with differing view angles). Regardless of the larger size of panoramic photographs, this type of photograph is observed more extensively and information extraction is expected to be enhanced. This finding is relevant for landscape studies based on photographs. Photo-questionnaires are more probable to yield more ecologically valid and detailed answers when panoramic photographs are used. Studies in which memorisation is required are also assumed to benefit from panoramic photographs as the enhanced information extraction is expected to improve recognition and memorisation.

The *characteristics of the landscape* tested in this dissertation all affect the viewing behaviour occurring in landscape photographs. Openness of the landscape seems to restrict the visual exploration as a result of the lack of clearly distinguishable objects in the fore- or middleground of the photographs. Instead, as open landscapes mostly consist of unbounded textures, people are more tempted to look at the horizon, which hampers an extensive scanning of the image. Objects present in the background (on the horizon), which are difficult to distinguish, explain the longer fixations encountered in open landscapes. In contrast to the level of openness, the degree of urbanisation of a landscape, which is positively correlated with the visual complexity of the landscape photographs, enhances visual exploration and generates more dispersed fixation patterns. This is probably an effect of the more varied and more complex character of more urbanised scenes. The greater information content, caused by the larger amount of colours and edges, could lead to a more exploratory visual behaviour as people tend to assimilate as much information as possible. When the degree of urbanisation decreases, this visual exploration becomes limited to the regions in the landscape photographs were buildings occur. Completely rural landscapes have been identified to deviate from this trend since extensive visual exploration patterns were found in these landscapes, despite their low information content and thus low visual complexity. In this case, it is plausible that as a consequence of the monotonous character of these landscapes, participants became bored and therefore started to search for interesting elements or started to make up their own task to complete the viewing time. Another possibility is that rural landscapes in which no buildings are present, elicited feelings of pleasantness and preference leading to an increased interest and thus an increased visual exploration, as proposed by Ulrich's model of affective response to natural scenes. These results are in line with our results found for homogeneous landscapes, which in our experiments corresponded to completely rural landscapes and in which an increased visual exploration was found as well in comparison to more heterogeneous landscapes (which did not contain completely urban scenes). The confirmed influence of landscape characteristics such as openness, urbanisation level and complexity/heterogeneity on the visual observation of landscape photographs is important knowledge for several reasons. First, it contributes to the variables' validity as criteria for visual landscape assessments as these variables have been demonstrated to lead to different perceptions of the landscape and thus to be discriminating factors in visual landscape classifications. Second, it indicates that people produce different viewing patterns depending on the type of landscape that is perceived. As a consequence, landscape changes are expected to have a different visual impact depending on the characteristics of the landscape in which they are introduced or performed. This knowledge is very valuable to take into account when deciding upon the location for implementing new infrastructures or constructions.

The *characteristics of the observer*, and more specifically the level of expertise in landscape related matters has been demonstrated to have a great deal of influence on how landscape photographs are observed. Landscape experts seem to scan the landscape images more extensively, making numerous but short fixations all over the landscape photograph. This is indicative of an enhanced information pick-up, very likely caused by expertise. According to the Information-processing theory, expertise results in an improved understanding of the environment, leaving more time for exploration. The visual behaviour of laymen, however, is much more restricted to a limited number of singular objects in the landscape, mostly buildings, which seem to catch and hold the attention. This is reflected in a lower amount of fixations, but of longer duration, and a restricted visual span. A possible explanation for the eye-catching nature of buildings can be found in the Gestalt principles of figure-ground and continuity as well as in the evolutionary Prospect-refuge theory. While experts depict a holistic viewing pattern of exploration and observer the landscape as a whole, non-experts mainly focus on specific features of the landscape. These findings indicate that experts indeed see the landscape differently from lay people and thus caution is necessary when considering experts' view as representative of the public's view. This result is not only useful for making experts aware of this divergence, it may also explain why assessments made by experts and laymen often disagree. As both groups look differently at the landscape, the information input on which decisions are based is different, which could explain the divergent opinions. However, this relationship remains to be investigated.

The fourth and final research question concerning the practical implications of eye-tracking research for landscape planning and design led to the development of an application for visual impact assessment of constructions. Since eye-tracking is a technique to measure viewing patterns, its most appropriate uses lies in the domain of visual impact assessment, a step in the planning process which is often given little or no attention. However, eye-tracking experiments are expensive, time-consuming and require a lot of expertise to be performed. As a consequence, results from eye-tracking studies cannot be quickly obtained. This is in conflict to the often urgent need for answers in practice, in which time is money. While for fundamental research, eye-tracking has proven to be very valuable and useful, this is not the case for its application in practice. However, some eye-tracking related tools such as the saliency maps presented in Chapter 5 have more potential because they are faster to produce, do not require a lot of expertise and do not necessitate participants. Saliency maps could be a helpful tool for objectively quantifying the level of visual integration of landscape changes. At the same time, since saliency maps have been demonstrated to be reliable predictions of the human viewing pattern in landscape photographs and the outcome of the saliency based method for visual impact assessment has been shown to correspond to human judgments of visual impact, they could be used to represent the public's view on the visual integration of new elements in the landscape.

In summary, we can conclude that the present dissertation is a contribution to landscape perception research as it investigates how landscapes are observed when represented on photographs. Insight into the viewing behaviour in landscape photographs has shown to be valuable for different reasons. It can be used to improve landscape studies which are based on landscape photographs and eye-tracking as a technique has been confirmed to be a very reliable and valuable approach for landscape perception research purposes. This opens new and broad horizons for further research as a whole set of landscape perception theories could be empirically tested. Finally, we believe that eye-tracking has a lot of potential to generate tools and applications which can be used in practice in the visual assessment branch of landscape planning and design.

While we intuitively sense the potential of eye-tracking for landscape perception research and applications, fundamental research on how eye-tracking can be used when studying landscapes and which aspects might influence the outcome of such studies is essential. This is what this dissertation was mainly concerned with. While eye-tracking had been used sporadically in landscape related research, a basic testing of the usefulness of the technique for the field of landscape research was still missing at the start of this dissertation in 2010. While we definitely do not claim to have completely filled up this gap, this research can be considered as an essential first contribution to the more fundamental knowledge concerning the use of eye-tracking in landscape perception research.

The Council of Europe defines landscape as “an area as perceived by people, whose character is the result of the action and interaction of natural and/or human factors”. Thus, landscape only gets significance when it is perceived. This perception mainly depends on our visual sense, our eyes, as 87% of the information is gained through sight. However, fundamental research on how people visually observe landscapes and which factors cause differences in observation is scarce. Therefore, the aim of this dissertation is to investigate in depth how people observe landscapes as represented on photographs. This is achieved by using eye-tracking, a technique which enables the registration of eye movements. The first part of the dissertation deals with the analysis of a number of factors influencing landscape observation. The acquired knowledge is relevant for landscape perception research in general as it formulates implications for landscape perception studies based on photographs and it contributes to the theories of landscape perception and experience. Finally, the results are valuable for landscape planning and design, in which the visual aspect plays an important role. In the second part, an eye-tracking related application for visual assessment of constructions in the landscape, based on attention predicting saliency maps, is developed and evaluated.

Factors influencing landscape observation

Three factors are expected to influence landscape observation: the characteristics of the landscape, the characteristics of the observer and the practical context. The characteristics of the landscape comprise aspects such as the degree of stewardship, coherence, disturbance, historicity, visual scale, imageability, complexity, naturalness and ephemera amongst others. The characteristics of the observer consist of socio-demographic aspects (e.g. gender, age, economic status, social class etc.) and socio-cultural variables (e.g. expertise and prior knowledge, ethnicity, religion, living environment etc.) as well as values and attitude. The practical context deals with the circumstances in which the observation takes place. Examples are the purpose with which the observation is executed, whether the landscape is observed on-site or on a representation of the landscape, which type of stimulus is used (e.g. photograph, virtual landscape representation, drawing) etc.

In the first part of this dissertation, we investigate how the three aforementioned factors influence landscape observation on photographs. Since not all variables of each factor could be examined, a selection was made. As a first research objective, the influence of the photograph properties, as a specific practical factor, on the visual landscape observation is analysed. Photographs differing in horizontal and vertical view angles are compared. In particular, a number of landscapes are represented as a panoramic photograph, a standard photograph, a detailed photograph (zoom 1), a more detailed photograph (zoom 2) and a wide angle photograph. The second research objective consists of investigating how different landscape characteristics affect landscape observation. Landscapes differing in degree of openness, heterogeneity and the level of urbanisation related to the visual complexity of the landscape photograph are analysed. The third research objective deals with the characteristics of the observer. In particular, the influence of landscape related expertise on the visual observation of landscapes is examined. A group of landscape experts, who acquired expertise through education or profession, and a group of laymen are compared.

To investigate these objectives, eye-tracking is used to objectively measure how people look at landscape photographs. This technique consists of sending low power infrared light into the eyes to enable the calculation of the point of gaze of the observer. Regions in the image which were observed can be identified via heat maps. In addition, the eye-tracking device registers numerous metrics based on fixations and saccades (eye movements). These provide useful information about the viewing behaviour and the exploration pattern occurring in the photographs. In the eye-tracking experiments, participants were asked to freely observe a number of landscape photographs for a fixed amount of time while their eye movements were registered. Statistical analyses were performed to detect differences in viewing pattern between the different groups of landscapes, observers and photograph types.

The results show a significant effect of the three factors under investigation. First, the photograph type seems to affect the viewing pattern in the sense that panoramic landscape photographs are observed more extensively, irrespective of their larger size. Information extraction is therefore expected to be improved. This is relevant knowledge for landscape perception studies based on photographs. The use of panoramic photographs in questionnaires will probably result in ecologically more valid and more detailed answers. Studies requiring memorisation will also benefit from using panoramic photographs as enhanced information pick-up is expected to facilitate recognition and memorisation tasks.

Second, the landscape characteristics ‘openness’, ‘heterogeneity’ and ‘the degree of urbanisation related to the visual landscape complexity’ all influence the observation patterns occurring in landscape photographs. Openness hampers the visual exploration, while complexity and heterogeneity which are positively correlated with the level of urbanisation, enhances an extensive visual exploration of landscape photographs. The demonstrated influence of these landscape characteristics on landscape observation is an important finding because it confirms the characteristics’ discriminating capacity and thus their validity as criteria for visual landscape classifications and assessments. In addition, the different viewing behaviours found in different landscape types indicate that landscape changes will probably have a different visual impact depending on the characteristics of the landscape in which they are to be introduced. This is valuable knowledge to consider when selecting locations for building new constructions while aiming at minimizing the visual impact on the landscape.

Finally, the characteristics of the observer and in particular landscape-related expertise has been demonstrated to lead to different landscape observation patterns. The more extensive scanning of the photographs, characterised by numerous but short fixations spread all over the image, occurring in landscape experts indicates an explorative viewing behaviour and an enhanced information extraction caused by expertise. Laymen, in contrast, display a more restricted visual exploration, focusing on a limited number of singular objects in the landscape. This finding is particularly important for participatory landscape planning as it indicates that experts and lay people observe the landscape differently. As a consequence, one should be cautious when considering experts' view as fully representative of the public's view. This also indicates the need for incorporating public participation in landscape assessment and planning processes.

Application in landscape planning and design

The fourth research objective of this dissertation is to investigate how eye-tracking related tools can be useful for landscape planning and design. In particular, the potential use of saliency maps, which are computationally generated predictions of the human viewing pattern based on the content of an image, is explored. Saliency maps thus allow us to predict which elements in an image will catch the attention and which will not. First, the reliability of saliency maps as predictions of the viewing pattern in landscape photographs is analysed. Human focus maps, obtained from an eye-tracking experiment, are compared to the corresponding saliency maps of the photographs. Second, a saliency based method for estimating the visual impact of constructions in the landscape is developed, applied and validated. The method consists of creating saliency maps of the original landscape photograph as well as of different scenario simulations in which new constructions are inserted. The correlation between the saliency map of the original landscape and the simulated landscape is calculated. High correlations indicate smooth visual integration from a landscape point of view. The distribution of the attention before and after the integration of the construction does not differ fundamentally. The construction does not catch the attention and thus the visual impact is low. Low correlations correspond to less integrated scenarios. Attention distribution before and after the intervention differs considerably. The new construction catches the attention and has a high visual impact. The method is applied to a number of simulations and the outcome is compared to human assessments of the visual integration of the simulations obtained from a photo-questionnaire.

The results show that saliency maps can be considered as reliable predictions of the human viewing pattern as significant correlations were found with human focus maps. Thus, saliency maps can be used in landscape planning and design and more specifically in the proposed saliency based method for visual impact assessment of constructions. This method was found to be useful and reliable for evaluating the visual impact of remote constructions in rural landscapes. It discriminates between scenario simulations of different colour and size and the results are consistent with human assessments of visual impact. It thus offers an objective way of visual assessment without the need to organize public consultation rounds in the early stages of the design process. Public participation, however, is still highly required when evaluating other aspects like accessibility, functionality, financial cost etc. The main advantage of the method is that it is a fast and easy method which makes testing of numerous simulations, created for different points of view, possible. Finally, it can be used either to achieve an optimal visual integration from a landscape point of view (highest correlation), either to obtain intentionally striking designs popping out of the surrounding landscape (e.g. landmarks) (lowest correlation).

In summary, it can be concluded that the dissertation provides a contribution to landscape perception research as it provides fundamental knowledge about how landscape photographs are observed and how this can be investigated using eye-tracking. Knowledge about the viewing behaviour in landscape photographs has been demonstrated to be valuable for different reasons and in different domains. Eye-tracking has been confirmed to be a reliable and valuable technique for studying landscape observation. However, new and broad horizons are still open to further research since a whole list of topics in landscape perception, could be investigated using gaze-tracking systems. This includes the empirical testing of theoretical concepts as well as the development of practical applications useful in the field of landscape planning and design.

De Raad van Europa definieert landschap als “een gebied zoals waargenomen door mensen, waarvan het karakter het resultaat is van de actie en interactie van natuurlijke en/of menselijke factoren”. Landschap krijgt dus enkel betekenis wanneer het waargenomen wordt. Deze waarneming wordt voornamelijk bepaald door de visuele zintuigen, de ogen, aangezien 87% van de informatie-opname uit de omgeving gebeurt via het zicht. Toch is fundamenteel onderzoek naar hoe mensen het landschap visueel waarnemen en welke factoren verschillen in observatie veroorzaken zeldzaam tot onbestaande. Het is dan ook de doelstelling van dit doctoraatsproefschrift in detail te onderzoeken hoe mensen landschappen, die voorgesteld zijn op foto, observeren. Hiertoe wordt gebruik gemaakt van eye-tracking, een techniek die het opnemen van oogbewegingen mogelijk maakt. In het eerste deel van het proefschrift worden een aantal factoren, die landschapsobservatie beïnvloeden, onderzocht. De resultaten van dit eerste deel zijn van belang voor het onderzoek naar landschapsperceptie in het algemeen aangezien de resultaten implicaties hebben voor landschapsonderzoek dat gebaseerd is op landschapsfoto’s. Daarnaast vormt de studie een bijdrage aan de theorieën die een rol spelen in landschapsperceptie en –beleving. Tenslotte zijn de resultaten ook waardevol voor landschapsplanning en –ontwerp daar het visuele aspect in dit toepassingsdomein een belangrijke rol speelt. In het tweede deel van het proefschrift wordt een eye-tracking gerelateerde toepassing voor het bepalen van de visuele impact van constructies in het landschap, ontwikkeld en geëvalueerd. Meer bepaald gaan we de bruikbaarheid van saliency maps als voorspellingen van het menselijk kijkpatroon na.

Factoren die landschapsobservatie beïnvloeden

Drie factoren worden verwacht een invloed te hebben op de observatie van landschappen: de kenmerken van het landschap zelf, de kenmerken van de waarnemer en de praktische context. De kenmerken van het landschap omvatten onder andere aspecten zoals de graad van onderhoud, coherentie, verstoring, historiciteit, visuele schaal, inbeeldingsmogelijkheid, complexiteit, natuurlijkheid en aanwezigheid van efemere fenomenen. De kenmerken van de waarnemer kunnen ingedeeld worden in socio-demografische aspecten (bijvoorbeeld geslacht, leeftijd, economische status, sociale klasse e.d.), socio-culturele factoren (bijvoorbeeld expertise en voorkennis, etniciteit, religie, leefomgeving e.d.) en levenswaarden en attitudes. Met de praktische context worden de omstandigheden waarin de observatie plaatsvindt bedoeld. Voorbeelden hiervan zijn het doel waarmee de observatie gebeurt, hoe het landschap wordt geobserveerd (ter plaatse of aan de hand van een voorstelling van het landschap), welk type stimulus wordt gebruikt (bijvoorbeeld foto’s, virtuele landschapsvoorstellingen, tekeningen) enzovoort.

In het eerste deel van dit doctoraatsproefschrift wordt onderzocht hoe de drie bovenvermelde factoren de observatie van landschapsfoto’s beïnvloeden. Omdat niet alle variabelen van elke factor onderzocht konden worden, werd een selectie gemaakt. De eerste onderzoeksdoelstelling analyseert welke invloed de fotokenmerken, als een specifieke praktische factor, hebben op de visuele observatie van het landschap. Het kijkpatroon in landschapsfoto’s met verschillende horizontale en verticale kijkhoeken wordt vergeleken. Meer concreet gaat het telkens om een panoramische foto, een standaard foto, een ingezoomde foto, een meer gedetailleerde zoom en een breedhoekfoto. De tweede onderzoeksdoelstelling onderzoekt hoe verschillende landschapskenmerken de visuele waarneming van het landschap beïnvloeden. Landschappen variërend in openheid, heterogeniteit en urbanisatiegraad, gekoppeld aan de visuele complexiteit van de landschapsfoto, worden geanalyseerd. In de derde onderzoeksdoelstelling wordt het effect van de kenmerken van de waarnemer, en meer bepaald van de aanwezigheid van landschapsgerelateerde expertise, op de observatie van landschappen bestudeerd. Het kijkpatroon van landschapsexperten (door opleiding of beroep) wordt vergeleken met het kijkpatroon van niet-experten.

Zoals reeds kort vermeld worden deze doelstellingen onderzocht door middel van eye-tracking. Dit systeem maakt gebruik van infrarood licht dat in de ogen van de waarnemer wordt gezonden. Op deze manier kunnen de oogbewegingen en dus ook de punten waarop de waarnemer focust, berekend worden. Zones die bekeken zijn, kunnen geïdentificeerd en voorgesteld worden door middel van heat maps. Bovendien registreert een eye-tracker een aantal metrieken die gebaseerd zijn op fixaties en saccades (oogbewegingen). Deze bieden waardevolle informatie over het kijkpatroon en de visuele verkenning van de beelden. In de eye-tracking experimenten uitgevoerd in dit doctoraat werden deelnemers gevraagd een aantal landschapsfoto's vrij (zonder opdracht) te bekijken gedurende een vastgelegd aantal seconden terwijl de oogbewegingen geregistreerd werden. De bekomen data werd nadien statistisch geanalyseerd om eventuele verschillen in kijkpatroon tussen tussen de verschillende groepen landschappen, waarnemers en fototypes na te gaan.

De resultaten tonen aan dat de drie onderzochte factoren alle een significante invloed hebben op het kijkpatroon. Ten eerste blijkt het fototype een effect te hebben in die zin dat panoramische foto's uitgebreider geobserveerd worden, ongeacht hun groter formaat. Dit wijst op een makkelijkere informatie opname wanneer dit type foto gebruikt wordt. Deze bevinding is belangrijk voor studies rond landschapsperceptie die gebruik maken van foto's. Antwoorden verkregen via enquêtes waarin panoramische foto's gebruikt worden, zullen namelijk waarschijnlijk gedetailleerder zijn en grotere gelijkenissen vertonen met enquêtes die in het landschap zelf afgenomen worden. Studies die memorisatie vereisen zullen allicht ook baat hebben bij het gebruik van panoramische foto's aangezien de vlottere informatie opname herkennings- en memorisatie-opdrachten vergemakkelijkt.

Ten tweede blijken alle geteste landschapskenmerken (openheid, heterogeniteit en graad van urbanisatie gekoppeld aan de visuele complexiteit van de landschapsfoto) een effect te hebben op de observatie van landschapsfoto's. Openheid beperkt de visuele exploratie terwijl complexiteit en heterogeniteit, die positief gecorreleerd zijn met de graad van urbanisatie, een uitgebreide visuele verkenning bevorderen. Het vastgestelde effect van deze landschapskenmerken op de landschapsobservatie is een belangrijk resultaat aangezien het de discriminerende capaciteit van deze kenmerken en dus hun geldigheid als criteria voor visuele landschapsclassificaties bevestigt. Bovendien tonen de verschillende kijkpatronen in de verschillende landschapstypes aan dat landschappelijke veranderingen zeer waarschijnlijk een verschillende visuele impact zullen hebben afhankelijk van het type landschap waarin ze geïntroduceerd worden. Dit is waardevolle informatie die in acht genomen moet worden wanneer locaties voor het bouwen van nieuwe constructies bepaald worden en de visuele impact op het landschap beperkt dient te blijven.

Ten slotte leiden de kenmerken van de waarnemer en in het bijzonder het beschikken over landschapsgerelateerde expertise tot verschillende kijkpatronen. De uitgebreidere visuele scanning van de foto’s door experten, gekenmerkt door veel maar korte fixaties verspreid over het hele beeld, duidt op een exploratief kijkgedrag en een makkelijkere informatie opname als gevolg van de aanwezige expertise. In tegenstelling tot experten vertonen niet-experten een veel beperktere visuele exploratie, waarbij vooral gefixeerd wordt op een beperkt aantal afzonderlijke objecten in het landschap. Dit is een belangrijk resultaat voor landschapsplanning waarin publieke participatie steeds meer aangemoedigd wordt. Aangezien experten en niet-experten het landschap op een verschillende manier bekijken, kan de observatie van experten dus niet volledig als representatief beschouwd worden voor deze van het bredere publiek. Dit bevestigt de onontbeerlijkheid van publieke participatie en dus de noodzaak aan het behoud ervan in planningsprocessen.

Toepassing in landschapsplanning en –design

Het onderzoeken van de bruikbaarheid van eye-tracking tools voor landschapsplanning en –ontwerp vormt het onderwerp van de vierde onderzoeksdoelstelling. In het bijzonder worden de mogelijke toepassingen van saliency maps verkend. Dit zijn computer-gegenereerde voorspellingen van het menselijk kijkpatroon gebaseerd op de inhoud van een beeld. Ze laten dus toe te voorspellen welke elementen in een beeld de aandacht zullen trekken en welke niet. Vooreerst wordt de betrouwbaarheid van saliency maps als voorspellingen van het menselijk kijkpatroon in landschapsfoto's nagegaan. Hiervoor werden menselijke focus maps (een type heat maps), verkregen op basis van een eye-tracking experiment, vergeleken met de overeenstemmende saliency maps van de foto's. Ten tweede werd een methode voor het bepalen van de visuele impact van constructies in het landschap, gebaseerd op het saliency principe, ontwikkeld, toegepast en gevalideerd. Hiervoor werden saliency maps gecreëerd van de originele landschapsfoto alsook van scenario simulaties waarin een nieuwe constructie geïntegreerd is. Vervolgens werd telkens de correlatie tussen beide bepaald. Hoge correlaties duiden op een optimale integratie vanuit landschappelijk standpunt. De spreiding van de aandacht voor en na het integreren van de constructie verschilt in dit geval niet fundamenteel. De constructie trekt met andere woorden weinig of geen aandacht en de visuele impact is klein. Lage correlaties stemmen overeen met minder goed geïntegreerde scenario's. Het aandachtpatroon voor en na de ingreep verschilt aanzienlijk. De nieuwe constructie trekt de aandacht en heeft dus een hogere kans op een grote visuele impact. De methode werd toegepast op een aantal simulaties en de uitkomst werd vergeleken met menselijke evaluaties van de visuele integratie, verkregen op basis van een foto-enquête.

De resultaten tonen aan dat de saliency maps als betrouwbare voorspellingen van het menselijke kijkpatroon beschouwd kunnen worden aangezien significante correlaties gevonden werden met menselijke focus maps. Saliency maps kunnen dus gebruikt worden in landschapsplanning en –ontwerp en meer bepaald in de voorgestelde methode voor het bepalen van de visuele impact van constructies. Deze methode werd na onderzoek bruikbaar en betrouwbaar bevonden voor het evalueren van de visuele impact van alleenstaande constructies in rurale landschappen. De methode discrimineert namelijk tussen scenario simulaties verschillend in kleur en grootte. Bovendien stemmen de resultaten overeen met menselijke evaluaties van de visuele impact. De methode biedt dus in de beginfase van het ontwerpproces de mogelijkheid om op een objectieve manier visuele evaluaties van nieuwe constructies uit te voeren zonder dat publieke consulatie-rondes noodzakelijk zijn. Participatie is echter wel nog steeds onontbeerlijk voor het evalueren van andere aspecten zoals toegankelijkheid, functionaliteit, financiële kost e.d. Het grote voordeel van de saliency methode is de snelle en makkelijke procedure die het testen van talrijke simulaties, gecreëerd voor meerdere standpunten, toelaat. De toepassing kan bovendien niet enkel gebruikt worden om een optimale visuele integratie te bekomen (hoge correlatie) maar ook voor het afleveren van ontwerpen die opzettelijk contrasteren met het omliggende landschap (bijvoorbeeld in het geval van landmarks) (lage correlatie).

Samenvattend kan men concluderen dat dit doctoraatsproefschrift een bijdrage levert aan het onderzoek rond landschapsperceptie aangezien het fundamentele kennis aanrijkt omtrent de observatie van landschapsfoto's en hoe dit kan onderzocht worden door middel van eye-tracking. Inzicht in het kijkpatroon in landschapsfoto's is waardevol voor landschappelijk onderzoek in het algemeen en voor landschapsplanning en –ontwerp in het bijzonder. Eye-tracking blijkt een betrouwbare en bruikbare techniek voor het bestuderen van landschapsperceptie. Hoewel in dit onderzoek reeds een aantal fundamentele aspecten van landschapsobservatie bestudeerd werden, zijn de mogelijkheden voor verder eye-tracking onderzoek zeer uitgebreid. Dit omvat bijvoorbeeld het empirisch testen van theoretische concepten alsook het ontwikkelen van praktische toepassingen die gebruikt kunnen worden in landschapsplanning en –ontwerp.

CURRICULUM VITAE

Lien Dupont was born in Geraardsbergen (Belgium) on the 10th of April 1987. In 2005 she graduated at the Immaculata Maria Instituut in Roosdaal and started to study Geography at Ghent University. In 2010 she obtained her Master's degree in Geography with great honours. Immediately after her graduation, she started working as a research and teaching assistant at the Landscape Research unit of the Department of Geography (Ghent University). In her job, she combined teaching activities with a PhD.

During her PhD, Lien presented her work at numerous international conferences around the world (IALE World 2011, 2015; ECLAS 2011, 2014; IAPS 2012, 2016; PECSRL 2012, 2014; IALE Europe 2013; ICA, 2013; ETRA 2014; ECEM 2015 etc.). For her research, she closely collaborates with researchers of the School of Computing at Clemson University (USA), of the Swedish University of Agricultural Sciences (Sweden) and of the University of Lyon (France). She is also first author of, amongst others, five papers that have been published in leading international peer-reviewed scientific journals.

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Table A: Real mean values corresponding to Table 2.2.

Table B: Real mean values corresponding to Table 2.3.

Table C: Real mean values corresponding to Table 2.4.

Table A: Real mean values corresponding to Table 2.2

Eye tracking metric	N	Real mean values per photograph type				
		panoramic	Standard	Zoom 1	Zoom 2	Wide angle
Number of fixations	83,001	15	14	14	14	14
Fixation duration	83,001	302	336	334	333	334
Number of saccades	81,300	15	13	13	13	13
Saccade amplitude	81,300	3.8	2.2	2.2	2.3	2.4
Saccade velocity	81,300	90.2	69.3	68.6	70.2	70.8
Observed horizontal area	2,070	880	388	385	381	388
Observed vertical area	2,070	150	163	164	172	167

Table A: Real mean values corresponding to Table 2.3

Eye tracking metric	N	Real mean values	
		Interest area on panoramic photograph	Standard photograph
Number of fixations	828	22	14
Fixation duration	828	299	983

Table A: Real mean values corresponding to Table 2.4

Eye tracking metric	N	Real mean values				
		Open	Semi-open	Enclosed	Homogeneous	Heterogeneous
Number of fixations	83,001	13	14	14	13	14
Fixation duration	83,001	332	326	324	329	326
Number of saccades	81,300	13	14	14	13	14
Saccade amplitude	81,300	2.6	2.5	2.6	2.73	2.49
Saccade velocity	81,300	74.8	73.4	74.2	75.5	72.8
Observed horizontal area	2,070	489	485	480	487	482
Observed vertical area	2,070	155	164	171	177	149